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VOLUME VI
Number 10

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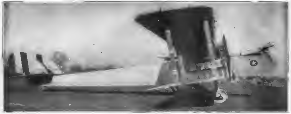

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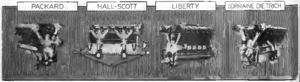

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JUNE 15, 1919 AVIATION AND AERONAUTICAL ENGINEERING VOL. VI. NO. 10

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AVIATION AND AERONAUTICAL ENGINEERING

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Vol. VI June 15, 1919 No. 10

NOW that the pioneer enterprise of the United States Navy has been brought to a happy conclusion with the arrival of the NC-4 at Plymouth, it is worth while to examine the lessons which the transatlantic flight has furnished to the aeronautical engineer.

First and foremost, this great flight fully demonstrated the practical value of the multi-engine boat-type seaplane for ocean service—a fact which had hitherto been open to serious doubt and the subject of much controversy. By successfully weathering storms both aloft and afloat the NC seaplanes have thoroughly proven to be airworthy as well as seaworthy craft, and the value of this demonstration will benefit aerial ocean transport no less than the naval service.

The second point which the transatlantic flight brought out is the desirability of building the hulls of large flying boats of steel instead of wood. This substitution would afford a more perfect flotation system because steel hulls do not absorb water when kept afloat for a considerable time, while on the other hand they are more unlikely to spring a leak through impact with the seas than a planked hull.

Finally, the experience of the NC-3 and of the NC-1 while afloat in a heavy sea near the Azores seems to indicate the advisability of fitting large flying boats with an auxiliary marine engine driving a marine propeller, so that in case of a failure of the aeronautical power-plant the craft could proceed on the surface under its own power like a motor boat. Aerial propellers do not satisfactorily fulfill this requirement because their high thrust makes the handling of the boat awkward in a heavy sea and also because at the high speed they are turning they are liable to be damaged by spray. The much greater fuel economy afforded in surface navigation by the use of a marine engine would furthermore insure to such a craft a cruising radius sufficiently great as to render them in most cases independent of outside assistance.

The Tandem Airplane

The question of the tandem type of airplane has periodically come to the fore ever since it was originated by the late Prof. Samuel P. Langley, and it is understood that one or two such machines are under construction at the time of writing.

Now that the Navy is considering the construction of a seaplane of much greater dimensions than the NC class and the English are reported to be contemplating the design of a twelve-engine machine, a distinct possibility exists for the employment of various multiplane combinations in airplanes of very large size.

The outstanding advantage of such a design, particularly of a tandem combination in biplane form, is that the span may be materially reduced. A gigantic span offers serious difficulties not only as regards maneuverability, but also from the viewpoint of weight of wing structure. There is a span beyond which the structural weight of the wing truss will increase more rapidly—by mere virtue of geometric and mechanical factors—than any refinement in construction can overcome.

It is at this point, therefore, that tandem wings may have a possible usefulness. However, it must be said that this type has up to now received little serious study. Its inherent defect lies in the inefficiency of the rear wings, as these are placed in the downwash of the front wings. Furthermore the weights are so spread out that controlability is not as good as in the single span wing type. Since the main weights will have to be placed rather close to the center of gravity, a great burden will be imposed upon the structure, while the moment of inertia, being naturally great, will require control surfaces somewhat larger proportionally.

All these are serious technical difficulties, though they should not be insuperable, and work along these lines might be well worth while if applied to a very large airplane.

The Atlantic to Pacific Flight

The proposed attempt of the Air Service to cross the United States in their greatest breadth from New York to San Francisco—a total distance of 2,750 miles—in two days is an endeavor worthy of the heartiest commendation. The airplane which will be used on this flight, the Martin bomber fitted with two Liberty engines, is like the victorious NC seaplanes, a distinctly American product and one that is immediately adaptable to the needs of aerial transport. Hence the proposed transcontinental flight assumes an importance far beyond that of a mere sporting venture and will, if successful, command serious attention in the circles concerned with the furtherance of commercial aeronautics.

It seems fitting in this connection to call attention to the excellent work which the Air Service has done since the signing of the Armistice in the matter of bringing the features of safety and reliability of the airplane to the attention of the public. The many long distance flights Air Service pilots daily undertake as a routine matter and succeed in carrying out without untoward incidents is the most convincing argument that may be given the public as to the value of the airplane in peaceful pursuits.

General Summary of the de Bothezat Blade-Screw Theory*

By Prof. George de Bothezat

Aerodynamical Expert, National Advisory Committee for Aeronautics

The blade-screw theory presented here gives explicit expressions for the slip and race velocities in the slip stream solely in function of the dimensions of the screw blades, the coefficient of fluid resistance of the different blade sections and the working conditions. The slip and race velocities once found the theory presents a complete picture of the whole phenomenon of working of a blade-screw, embracing all the states of work possible for a blade-screw. The following system of equations constitutes the basis of the theory.

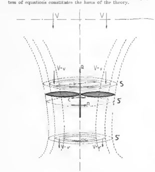


Fig 1

Let us neglect the radical velocities and consider the elements of the n blades contained in an annulus limited by two surfaces of revolution which are the locus of the stream lines of the mean velocities of the slip stream. Let us consider two sections of the slip stream, one S in the indraught quite close to the blade-screw, another S'' in the outdraught at the narrowest section of the slip stream (see Fig 1) and let us consider the axial and tangential components of the fluid particles in the slip stream in their motion relatively to the blade screws.

We will use the following notation:—

$V + v$ axial velocity of the fluid relatively to the screw at section S.

V screw translation velocity.

v slip velocity.

$r(\Omega - \omega)$ tangential velocity of the fluid relatively to the screw at section S

Ω angular velocity of screw rotation

$r\omega$ race velocity.

The slip and race velocities v and $r\omega$ are functions of the distance r of the fluid particles from the screw axis.

Similarly at the section S'' we have the velocities
$$(V+v'') \text{ and } r''(\Omega-\omega'')$$

ΔM fluid mass that flows in a unit of time through an annulus

ΔI and $\Delta I''$ moments of inertia of the mass ΔM at the sections S and S'' respectively

ΔS and $\Delta S''$ areas of the annulus at the sections S and S''

δ fluid density considered constant in the whole fluid mass.

We have

Equation of continuity for the flow in the slip stream

$$\Delta M = \Delta S(V+v)\delta = \Delta S''(V+v'')\delta \tag{1}$$

Geometrical relations

$$\Delta I = \Delta M r^2,\quad \Delta I'' = \Delta M r''^2 \tag{2}$$

From the similitude of the flow conditions in the sections S and S''

$$\frac{\Delta S}{\Delta S''} = \frac{V+v''}{V+v} = \frac{r^2}{r''^2} = \frac{\Delta I}{\Delta I''}$$

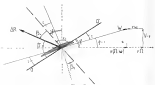


Fig. 2

The theorems of momentum and moments of momentum applied to the slip stream give for

(3) The partial thrust $\Delta Q = \Delta M v''$

(4) The partial torque $\Delta C = \Delta I''\omega''$

or

$$\Delta Q = \Delta S(V+v)v''\delta \tag{5}$$

$$\Delta C = \Delta S r^2 \omega'' \frac{(V+v)^2\delta}{(V+v'')} \tag{6}$$

and

$$\rho = \frac{V\Delta Q}{\Omega\Delta C} = \frac{V}{r\Omega}\,\frac{v''(V+v'')}{r\omega''(V+v)} \tag{7}$$

The last quantity may be termed the *specific function*. In case of a propulsive screw it is the *partial efficiency*.†

Considering the direct action of the fluid on the screw blades we find (see figs 2 and 3)

$$\Delta Q = n\Delta R \operatorname{Cos}(\varphi+\beta_\lambda) \tag{8}$$

$$\Delta C = nr\Delta R \operatorname{Sin}(\varphi+\beta_\lambda) \tag{9}$$

with $\Delta R = k_i\,\delta\Delta A W^2$

where k_i is the fluid resistance coefficient of the considered blade section

ΔA is the area of the considered blade element $\Delta A = b\Delta r$

b is the breadth of the considered blade section

$W^2 = (V+v)^2 + r^2(\Omega-\omega)^2 \quad k_i\delta = \sqrt{K_x^2+K_y^2},\ \beta = \operatorname{arctg}\frac{K_x}{K_y} - i$

$$\rho = \frac{V\Delta Q}{\Omega\Delta C} = \frac{V}{r\Omega}\,\frac{1}{tg(\varphi+\beta)} \tag{10}$$

Comparing (5) and (6) to (8) and (9), taking account of the relationships

$$\Delta S = 2\pi r\Delta r,\ \Delta A = b\Delta r \quad W^2 = \frac{(V+v)^2}{\operatorname{Sin}^2(\varphi-i)}$$

* The complete memoir is published by the National Advisory Committee for Aeronautics.

† I call *partial efficiency* the efficiency of a blade section.

and using the notation
$$a = \frac{nb}{2\pi r}$$
which quantity we call *breadth ratio*, we find

$$\frac{v''}{V+v} = \frac{a\,k_i \operatorname{Cos}(\varphi+\beta)}{\operatorname{Sin}^2(\varphi-i)} \tag{11}$$

$$\frac{r\omega''}{V+v'} = \frac{a\,k_i \operatorname{Sin}(\varphi+\beta)}{\operatorname{Sin}^2(\varphi-i)} \tag{12}$$

An investigation of the question shows that the rotational motion of the fluid in the slip stream has only a slight influence on the translational motion of the same. Under such conditions not only the last relation takes place, but we also have

$$v\Delta Q = \tfrac{1}{2}\Delta M v''^2,\quad \omega\Delta C = \tfrac{1}{2}\Delta I''\omega''^2$$

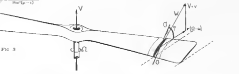


Fig 3

When it is noted that the work used for the displacement of the blades in the fluid is equal to the work of the screw-blades fluid resistance in their motion relatively to the fluid, the theorem of kinetic energy is expressed by the relation

$$\Omega\Delta C = V\Delta Q + \tfrac{1}{2}\Delta M v''^2 + \tfrac{1}{2}\Delta I''\omega''^2 + [\Omega\Delta C - V\Delta Q - \omega\Delta C - v\Delta Q]$$

from which follows‡

$$v\Delta Q + \omega\Delta C = \tfrac{1}{2}\Delta M v''^2 + \tfrac{1}{2}\Delta I''\omega''^2$$

(‡) If we denote by ρ_r the losses in impact and friction for the considered blade section it will be easy to see that we have
$$\Omega\Delta C = V\Delta Q + \tfrac{1}{2}\,\Delta M v''^2 + \tfrac{1}{2}\,\Delta I''\omega''^2 + \rho_r$$
But on the other hand evidently
$$\rho_r = \Omega\Delta C - V\Delta Q - \omega\Delta C - v\Delta Q$$
and thus the foregoing relation is justified

from which follows by (3) and (4)

$$v'' = 2v \quad \omega'' = 2\omega \tag{13}$$

These last relations have to be considered as the definition of the slip stream section S. Substituting the last values in the relations (11), (12) and (7) we get

$$\frac{2v}{V+v} = \frac{a\,k_i \operatorname{Cos}(\varphi+\beta)}{\operatorname{Sin}^2(\varphi-i)} \tag{14}$$

$$\frac{2r\omega}{V+2v} = \frac{a\,k_i \operatorname{Sin}(\varphi+\beta)}{\operatorname{Sin}^2(\varphi-i)} \tag{15}$$

$$\rho = \frac{V}{r\Omega}\,\frac{v(V+2v)}{r\omega(V+v)} = \frac{V}{r\Omega}\,\frac{1}{\operatorname{tg}(\varphi+\beta)} \tag{16}$$

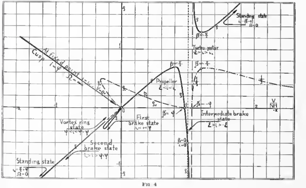


Fig 4

Let us call *relative pitch* the ratio

(17) $$x = \frac{V}{NH}$$

let us note the relations

$$H = 2\pi r \operatorname{tg} \varphi, \quad \Omega = 2\pi N$$

and designate by ax the expression

(18) $$\frac{a\, k_1 \operatorname{Cos}(\varphi+\beta)}{2 \operatorname{Sin}^2(\varphi-i)} = ax$$

(22) $$\rho = \frac{V \Delta Q}{\Omega \Delta C} = x \frac{\operatorname{tg} \varphi}{\operatorname{tg}(\varphi+\beta)} = \frac{(1-ax) \operatorname{tg}(\varphi-i)}{\operatorname{tg}(\varphi+\beta)\, [1+ax(1+ax) \operatorname{tg}(\varphi+\beta) \operatorname{tg}(\varphi-i)]}$$

(19) $$v = V \frac{ax}{1-ax} = r\Omega \frac{ax}{1-ax} \rho \operatorname{tg}(\varphi+\beta)$$

(20) $$r\omega = \frac{ax(1+ax)}{1-ax} V \operatorname{tg}(\varphi+\beta) = r\Omega \frac{ax(1+ax)}{1-ax} \rho \operatorname{tg}^2(\varphi+\beta)$$

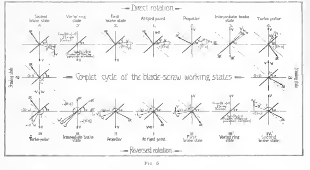


Fig 5

From (14) and (15) we directly find the values of the slip and race velocities

(19) $$v = \frac{Vax}{1-ax} = r\Omega \frac{ax}{1-ax} x \operatorname{tg} \varphi$$

(20) $$r\omega = \frac{ax(1+ax)}{1-ax} V \operatorname{tg}(\varphi+\beta) = r\Omega \frac{ax(1+ax)}{1-ax} x \operatorname{tg} \varphi \operatorname{tg}(\varphi+\beta)$$

Substituting these last values in

$$\operatorname{tg}(\varphi - i) = \frac{V+v}{r(\Omega-\omega)}$$

we get

(21) $$x = \frac{(1-ax) \operatorname{tg}(\varphi-i)}{\operatorname{tg} \varphi\, [1+ax(1+ax) \operatorname{tg}(\varphi+\beta) \operatorname{tg}(\varphi-i)]}$$

(22) $$\rho = x \frac{\operatorname{tg} \varphi}{\operatorname{tg}(\varphi+\beta)}$$

For the partial thrust and torque we find the values

(23) $$\Delta Q = 2\Delta S v(V+v)\delta = \frac{2ax}{(1-ax)^2} \delta \Delta S V^2 = q \delta \Delta S V^2$$

(24) $$\Delta C = \Delta Q r \operatorname{tg}(\varphi+\beta)$$

where

(25) $$q = \frac{2ax}{(1-ax)^2}$$

is the so called *load coefficient*

In Fig 4 is represented the specific function ρ in function of the relative pitch x This curve is nothing but the analytical extension of the efficiency curve of the propulsive screw

We have thus reached the fundamental system of equations

(18) $$ax = \frac{v}{V+v} = \frac{a\, k_1 \operatorname{Cos}(\varphi+\beta)}{2 \operatorname{Sin}^2(\varphi-i)}$$

(21) $$x = \frac{V}{NH} = \frac{(1-ax) \operatorname{tg}(\varphi-i)}{\operatorname{tg} \varphi\, [1+ax(1+ax) \operatorname{tg}(\varphi+\beta) \operatorname{tg}(\varphi-i)]}$$

(23) $$\Delta Q = 2\delta \Delta S(V+v)v = q\, \delta \Delta S V^2$$

(24) $$\Delta C = \Delta Q\, r \operatorname{tg}(\varphi+\beta)$$

(25) $$q = \frac{2ax}{(1-ax)^2}$$

the discussion of which leads to the following results

A blade screw can undergo 16 states of work, 8 of direct rotation and 8 of reversed rotation (see Fig 5).

The states of work of direct rotation are

a—Standing state
The blade screw is at rest in a fluid flow; the acting torque is equal to the resistance torque

4'—Second brake state
Case of hydraulics brakes for examples

3'—The vortex ring state.
This state of work was discovered by the present theory It is characterized by the formation of a vortex ring in the outdraught. The blade screw itself produces a braking action The beginning of the vortex ring state is marked by the whirling phenomenon, when the thrust disappears and its end marks the change of direction of the stream flowing through the area swept by the screw blades The cusp on the curve of the specific function corresponds to the whirling phenomenon

2'—First brake state
Case of braking the ship motion by the blade screw for example

1—Work at fixed point
Fans, helicopter or lifting screws helicoidal pumps

2—Propulsive state of work
Air and marine propellers

3—Intermediate brake state

4—Turbo motor state Turbines, wind mills, etc

The states of work of reversed rotation constitutes, so to say, the reflected picture of the states of work of direct rotation The specific function unites in a continuous whole all the system of states of work of the blade screw The infinite and zero points of the specific function disconnect one from another the different states of work, and the maxima and minima points correspond to the maxima efficiency of the corresponding states.

All the consequences of the fundamental system of equations of the blade screw theory will be developed in a series of memoirs. The first memoir contains a general discussion of the sixteen states of work of the blade screw and a complete quantitative study of the propulsive screw The principal results obtained for the propulsive screw are

The working of a blade-screw at fixed point is characterized by the following system of equations

(26) $$ax = 1$$

(27) $$a = \frac{nb}{2\pi r} = \frac{2 \operatorname{Sin}^2(\varphi - i_0)}{k_1 \operatorname{Cos}(\varphi+\beta_0)}$$

(28) $$\rho_0 = \frac{\frac{1}{2}\Delta M e_0'^2}{\Omega \Delta C} = \frac{\operatorname{tg}(\varphi-i_0)}{\operatorname{tg}(\varphi+\beta_0)\, [1+2 \operatorname{tg}(\varphi-i_0) \operatorname{tg}(\varphi+\beta_0)]}$$

(29) $$e_0 = r\Omega_0 \rho_0 \operatorname{tg}(\varphi+\beta_0), \quad r\omega_0 = 2r\Omega_0 \rho_0 \operatorname{tg}^2(\varphi+\beta_0)$$

(30) $$\Delta Q_0 = 2\delta \Delta S v_0^2 = 2\delta \Delta S r^2 \Omega_0^2 \rho_0^2 \operatorname{tg}^2(\varphi+\beta_0)$$

(31) $$\Delta C_0 = 2\delta r \Delta S r^2 \Omega_0^2 \rho_0^2 \operatorname{tg}^3(\varphi+\beta_0)$$

(32) $$\rho_0 = \frac{e_0 \Delta Q_0}{\Omega_0 \Delta C_0}$$

Equation (26) expresses the fundamental fact, that *for a blade screw working at fixed point the angles of attack of all the blade sections have constant values independent of the angular velocity of the screw rotation.* The general configuration of the slip stream depends only on the size and shape of blades.

Three kinds of losses have to be considered for a blade screw.

I—The fan losses $$p_v = \frac{\frac{1}{2}\Delta M e'^2}{\Omega \Delta C} = \rho \frac{v}{V} = \rho \frac{ax}{1-ax}$$

II—The vortex losses $$p_t = \frac{\frac{1}{2}\Delta I'' \omega'^2}{\Omega \Delta C} = \frac{\omega}{\Omega}$$

III—The resistance losses $$p_r = \rho \frac{\operatorname{tg}(\varphi+\beta) - \operatorname{tg}(\varphi-i)}{(1-ax) \operatorname{tg}(\varphi-i)}$$

The total losses are the sum of the foregoing losses.

$$p = p_v + p_t + p_r = 1 - \rho$$

For the load coefficient we find the expression

$$q = 2\frac{p_v}{\rho}\left(1 - \frac{p_v}{\rho}\right)$$

The study of the working conditions of a blade section leads to the following conclusions

The partial efficiency of each blade section depends on its configuration The partial efficiency is a maximum when the fluid resistance ΔR is normal to the zero line of the considered section The *optimum angle of attack* is the incidence which corresponds to that orientation of ΔR. The smaller the optimum angle of attack the bigger is the partial efficiency of the considered blade section This last condition gives us a criterion for the selection of blade sections.

The condition of absence of screw blades interference is expressed by

$$\nu a \leq \operatorname{Sin} \varphi$$

where ν is an experimental coefficient.

A geometrical method, self evident from fig 6, is used to show the connections between the total efficiency η and the partial efficiencies ρ

Going over to the integration of the work of all the blade elements we find

The thrust $Q = \Sigma \Delta Q = \delta V^2 \Sigma q \Delta S = \pi \delta V^2 \int q d(r^2) = \pi \delta V^2 I_1$

The torque $C = \Sigma \Delta C = \frac{\delta V^2}{\Omega} \Sigma \frac{q}{\rho} \Delta S = \frac{\pi \delta V^3}{\Omega} \int \frac{q}{\rho} d(r^2) = \frac{\pi \delta V^3}{\Omega} I_2$

and also

The thrust power $L_u = QV = \pi \delta V^3 I_1$

The torque power $L_2 = C\Omega = \pi \delta V^3 I_2$

where

$$I_1 = \int q d(r^2), \quad I_2 = \int \frac{q}{\rho} d(r^2)$$

The total efficiency $\eta = \frac{I_1}{I_2}$

The condition of maxima of the total efficiency fixes the best shape to be given to the blades; this last question thus appears as a problem of calculus of variations.

The integrals I_1 and I_2 are functions only of the ratio V/N, which we call *advance* and designate by μ

$$\frac{V}{N} = \mu$$

It thus follows that

$$\frac{Q}{V^2} = \pi\delta I_1(\mu), \quad \frac{L_2}{V^3} = \pi\delta I_2(\mu)$$

Comparing the work of the blade screw when advancing to its work at fixed point we find

$$Q = \pi \delta \Omega^2 \int q' d(r^4) = \pi \delta \Omega^2 I'_1$$
$$L_2 = \pi \delta \Omega^3 \int q' \operatorname{tg}(\varphi+\beta) d(r^4) = \pi \delta \Omega^3 I'_2$$

with

$$q' = \frac{ax \operatorname{tg}^2(\varphi-i)}{[1+ax(1+ax) \operatorname{tg}(\varphi+\beta) \operatorname{tg}(\varphi-i)]^2}$$
$$I'_1 = \frac{\mu^2}{4\pi^2} I_1, \quad I'_2 = \frac{\mu^3}{8\pi^3} I_2$$

and

$$Q_0 = \pi \delta \Omega_0^2 \int q'_0 d(r^4) = \pi \delta \Omega_0^2 C_1$$
$$L_0 = \pi \delta \Omega_0^3 \int q'_0 \operatorname{tg}(\varphi+\beta_0) d(r^4) = \pi \delta \Omega_0^3 C_2$$
$$q'_0 = \frac{\operatorname{tg}^2(\varphi-i_0)}{[1+2 \operatorname{tg}(\varphi+\beta_0) \operatorname{tg}(\varphi-i_0)]^2}$$

so that

$$\frac{Q}{Q_0} = \frac{\Omega^2}{\Omega_0^2} \frac{I'_1(\mu)}{C_1}, \quad \frac{L_2}{L_0} = \frac{\Omega^3}{\Omega_0^3} \frac{I'_2(\mu)}{C_2}$$

where C_1 and C_2 are two constant which depend only on shape and size of the blades

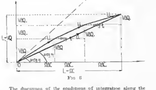


Fig 6

The discussion of the conditions of integration along the blades leads us to the consideration of different kinds of blade-screws, such as blade-screws with uniform ventilation, blade-screws with maximum total efficiency, etc.

The problem of blade-screw design is solved in its most general form Special nomograms are established for that purpose, which give the direct solution of all the relations that occur in the blade-screw design problem.

Afterwards the theory of uniform families of blade-screws is established. This theory gives the complete solution of the screw selection problem. The new standpoint adopted is the classification of screw first in *uniform families* characterised by the similitude of the blades when all their sections are brought to have a pitch equal to zero, and afterwards in varieties characterized by the same system $S(i)$ of the angles of attack under which the different blade sections are working Three principal varieties have to be distinguished, *the optima or maxima variety*, characterized by the system $S(i_0)$ of the optima angles of attack, the *minor variety*, whose angles of attack $S_1(i)$ are all smaller that the optima angles and major variety whose angles of attack $S_2(i)$ are all bigger than the optima angles of attack

For all the screws of the same variety of the same uniform family the quantities H/D, $N^2L_2/\pi\delta V^3$ and η are all functions of V/ND only, that is

$$H/D = A(V/ND), \quad \frac{N^2 L_2}{\pi \delta V^3} = B(V/ND), \quad \eta = C(V/ND)$$

If we draw a family of at least three systems of curves A, B, C for a minor, optima and major variety of the same uniform family, we will get a diagram allowing to find directly the pitch H and the diameter D of the most convenient blade-screw for a given case. It has to be noted that to the working conditions L_a, V and N corresponds in a given screw family an infinity of screws. Our method of screw selection gives the curve of the pitches H in function of the corresponding diameters D. For airplanes minor screws have to be always adopted, for tugs optimum screws.

At the end of this first memoir a new method is given for the measurement of the coefficients of fluid resistance by aid of a new kind of screw which is called *plane radial screw* the test of which at fixed point gives the values of the coefficients K_x and K_y corresponding to the section adopted for the plane-radial screw blades.

The plane-radial screw is defined by the conditions:

$$\rho = \text{const} \quad \alpha = \text{const}, \; k_1 = \text{const}$$

along the blades.

The blades of the plane-radial screw are thus simply not twisted boards limited by two radial lines and having all their sections geometrically similar. The thickness of the plane-radial screw blades thus goes increasing from boss to tip proportionally to the blade breadth.

It will be easy to see that for a plane radial screw working at fixed point we have

(33) $$Q_\phi = \pi \delta \rho_0^2 \Omega_0^2 \, tg^2 (\varphi + \beta_0) [r_2^4 - r_1^4]$$

(34) $$C_\phi = {}_{4/5} \pi \delta \rho_0^2 \Omega_0^2 \, tg^2 (\varphi + \beta_0) [r_2^5 - r_1^5]$$

where r_2 is the blade radius at the tip and r_1 the blade radius at the boss, and also

(35) $$C_\phi / Q_\phi = {}_{4/5} \, tg (\varphi + \beta_0) \frac{r_2^5 - r_1^5}{r_2^4 - r_1^4}$$

When for a plane radial screw, of a given blade section we have measured Q_ϕ and C_ϕ from relation (35) we get tg $(\varphi + \beta_0)$. Knowing tg $(\varphi + \beta_0)$ we find ρ_0 from relation (33), and knowing ρ_0 and tg $(\varphi + \beta_0)$ from relation (28) we find tg $(\varphi - \iota_0)$. At the end knowing tg $(\varphi + \beta_0)$ and tg $(\varphi - \iota_0)$ from relation (27) we find k_1. Let us designate by ψ the angle of inclination of the chord of a blade section on the plane of screw rotation, and by γ the angle between that chord and the corresponding zero line. We have

$$\varphi = \psi + \delta, \quad \alpha = \iota - \gamma$$

where α is the angle of attack measured from the chord. If we have found

$$\varphi + \beta_0 = \psi + \gamma + \beta_0 = c_1$$
$$\varphi - \iota_0 = \psi + \gamma - \iota_0 = \psi - \alpha = c_2$$

we will have

$$\alpha = \psi - c_2$$

ψ being a known angle. Giving different values to ψ we will be able to trace the curve of

$$k_1 = F(\alpha)$$

The intersection of this curve with the abcissa axis will give us the value of γ and thus we will have

$$\beta_0 = c_1 - \psi - \gamma$$
$$\iota_0 = c_2 - \psi - \gamma$$

From the value of k_1 and β_0 in function of ι_0 it will be easy to deduce the curves of K_x and K_y.

For the measurement of the coefficients of fluid resistance by aid of this method it is thus sufficient to use two plane radial boards having for cross section the desired profile, and to adjust them as blades to a boss under different values of ψ. The measurement of Q_ϕ and C_ϕ of such a plane radial screw at fixed point will thus give us, as above shown, the curves of k_1 and β_0 and K_x and K_y. This method thus appears to be the most simple and convenient method for the measurement of the fluid resistance coefficients in exactly the same conditions as of the screw blades working and this in any kind of fluid. This short summary thus shows the whole scope of the present theory and its important possibilities.

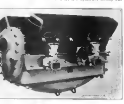
In conclusion, I cannot refrain from expressing the wish to see special laboratories set apart for the particularized study, in the light of the present theory, of the blade screw, the domain of which is as novel as it is all-important from the view point of social economy. The great importance of this problem readily appears in view of the manifold uses to which blade screws are put in shipping and in aeronautics, not to speak of other applications, such as fans, turbines, etc., and enables us to visualize the enormous supplies of energy which are daily brought within our reach by the agency of blade screws. The power of marine and air fleets is directly dependent on the efficiency of the screws employed, for every increase in efficiency represents an equivalent saving of many million gallons of fuel. The importance of improving the efficiency of blade screws by means of a thorough scientific investigation is thus self-evident, and no factor which may contribute to their greater perfection should be neglected.

The results obtained by the present theory will prove of practical value the sooner special organizations suitably equipped for this research work will come into being. The principal aim of these establishments should be the standardizing, under the direction of competent specialists, of all screws employed for the requirements of the mechanical arts, as well as their further development along strictly scientific lines.

Fiat 12-cyl. 400 hp. Engine

The latest type of aviation engine to be produced by the Fiat Co. is a particularly interesting 12-cyl. model developing 400 hp. In this new engine the designers have succeeded in obtaining great accessibility, reduced overall area, low weight per horsepower, and in producing a remarkably "clean" engine.

The cylinders, which have a bore of 120 mm. and a stroke of 150 mm., are of steel, with a common water jacket for each group of six. The valves are placed in the cylinder head, but



Side View of the Fiat 12 Cyl. 400 Hp. Airplane Engine, Showing the Geared Down Propeller Drive

are covered by a metal housing which adds to the clean appearance of the engine and prevents any oil leakage. Operation of the overhead camshafts is by means of a vertical shaft and bevel gearing for each group of cylinders.

There are four carburetors, carried on the outside of the cylinders, in which position they are immediately accessible by removing the sides of the engine housing. Equal accessibility is obtained for the magnetos by driving them from a central cross shaft, each magneto thus being placed between two carburetors. With this design complete accessibility is had by the mere removal of the engine housing, to the carburetors, the plugs, and the magnetos, the only parts likely to require frequent attention.

The propeller is of the geared down type, with a ratio of 1 to 1.51, and for war purposes was designed for a gun to be fired through it. Normal engine speed is 2300 r.p.m., at which speed 400 hp. is developed. At the maximum engine speed of 2500 r.p.m. the horsepower is 450. Weight of the engine empty is 770 lb.; weight with cooling water is 826 lb., weight with all on is 890 lb. Weight per horsepower, with water and radiator is 1.9 lb. The engine has a gasoline consumption of 8.4 oz. per hp./hr., and a minimum consumption of 7.7 oz. per hp./hr.

Airplane Engine Crankshaft Design

By Glenn D. Angle

It has been truthfully stated many times that every engine design is a compromise and does not necessarily represent an aggregation of the best components. However, to obtain the best engine design, careful consideration must be given to each detail and the combination of the various elements should be correctly made and involve the least amount of sacrifice. Some elements bear a closer relationship to the whole design than others, and therefore require more particular attention.

The crankshaft is one of these important details. The simple treatment which follows is only intended to cover that part of crankshaft design which relates to and effects engine design in general, particularly airplane engine design. A study of various types of crankshafts having different numbers of main journals, as well as crankshaft bearings and their lubrication are in reality special subjects, and although demanding very careful consideration, the designer must first have a general knowledge of the crankshaft problems met with in airplane engines, and also, a stress analyses applicable to any shaft.

Manufacture

Airplane engine crankshafts, except the radial and rotary types, do not differ perceptibly from those generally found in automobile and marine engines. The materials and workmanship, however, are necessarily of a much higher quality. The low weight per horsepower, peculiar to airplane engines, prohibits the use of any material other than high grade drop-forged steel for the crankshafts. The forgings are usually made in dies when the quantity warrants it, but cases are known where numbers of shafts have been cut from large billets which have been forged under an ordinary drop hammer. Making a crankshaft from such a forging entails a great amount of rough machine work; nevertheless for experimental shafts, time can be saved by this method as considerable labor is required in making a crankshaft die.

Dies made from cast iron are inexpensive and easily made and may be used to good advantage when only a few forgings are required. The forgings are practically identical with those made in permanent production dies. Due to the grain of the material being more properly formed, shafts made in these temporary dies should excell those cut from billets, for important experimental work. There is a very narrow margin, however, when considered from a time and cost basis, between cutting shafts from ordinary forgings and making a die which has such a short period of usefulness. Cast iron dies are undoubtedly of the most value in making experimental six and twelve cylinder crankshafts which have throws 120 degrees apart.

The shafts should be accurately machined all over in order to save weight and obtain static balance. Fractures are usually started by deep marks, so by removing these, the danger of breakage is greatly eliminated. The crankpins and journals are ground to close limits thus enabling the bearings to be more easily fitted with the proper clearances.

Materials

It is essential that the physical properties of the steels specified for crankshaft forgings be strictly adhered to. Careful analysis on the part of the designer is of little value if the necessary factors of safety which have been allowed are lowered by the substitution of inferior or defective material. Rigid inspection is demanded for each piece during the various processes required to produce a finished crankshaft.

Owing to the amount of machine work involved in manufacturing a crankshaft, the metal should be no harder than is consistent with its properties of toughness and strength. The latter qualities are obtained by heat treating the steel. Crankshaft material used in the better grade of engine has, after being heat-treated, a tensile strength of 150,000 to 175,000 lb. per sq. in. with a corresponding elastic limit of 125,000 to 150,000 lb. per sq. in. and a modulus of elasticity between 30 and 40 millions.

The chemical analyses may be varied to suit the requirements providing the proper heat-treatments are employed in producing the necessary physical properties. The steels generally employed are commonly known as 3½ per cent nickle, chrome-nickle and chrome-vanadium. Of these three the first is probably the easier to machine. It may contain from .25 to .40 per cent of carbon, .50 to .80 per cent of manganese, not over .04 per cent of phosphorus or .045 per cent of sulphur and from 3.25 to 3.75 per cent of nickle. Quite a number of steel analyses may give what is known as chrome-nickle steel. The amount of carbon may range from .25 to .45 per cent, manganese from .30 to .80 per cent, phosphorus and sulphur should not be present in quantities over .04 and .045 per cent respectively, nickle from 1 per cent as high as 5 per cent and chromium ranging in quantities from .45 to 1.5 per cent. The analyses of chrome vanadium varies from the first specified only in that chromium in quantities of from .80 to 1.1 per cent and vanadium of not less than .15 per cent is present instead of nickle.

Weight

The weight of the crankshaft forms a relatively large part of the total weight of the engine and it naturally follows that the design of any shaft should be made with the view of keeping its weight as low as possible. This must never be done however, at the slightest sacrifice of strength. The number and

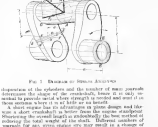


Fig. 1. Diagram of Stress Analysis

disposition of the cylinders and the number of main journals determines the shape of the crankshaft, hence it is only essential to provide metal where strength is needed and omit it in those sections where it is of little or no benefit.

A short engine has its advantages in plane design and likewise a short crankshaft is better from the engine standpoint. Shortening the overall length is undoubtedly the best method of reducing the total weight of the shaft. Different numbers of journals for any given engine size may result in a change of weight but this is primarily a problem in bearing design.

Stress Analysis

The crankshaft, while performing its function of transmitting the power of the engine to the driving member in the form of torque, is under very severe strains and it is therefore quite important that the stresses occurring from all known sources be thoroughly analyzed and kept within safe limits. Failure in this important member can be avoided by providing ample dimensions consistent with the materials employed.

Due to the shape of the crankshaft, load applications introduce stresses of a complicated nature. These stresses are difficult to determine exactly, but results within practical limits can be obtained by following the action of a single throw crank under tension. Let this represent the crank throw nearest the driving end, transmitting the maximum instantaneous power of a multi-cylinder engine under a force applied at the crankpin. The nature of the various stresses in the journals, crankpins and cheeks are illustrated in Fig. 1, the deflections being exaggerated for the purpose of showing their effects. This action can be easily verified by twisting a flexible model, preferably one made from thin flat stock, about the axis of its journals.

It is interesting to note that the same degree of bending and torsion occurs in similar sections on either side of AA. The crankpin nearly assumes an S-shape and at the same time is under torsional deflection. The cheeks are bowed in opposite directions and twisted at the same instant. The journals are under the same degree of torsional deflection as the crankpin and while held in place by the bearings are resisting the bending strains as would a simple beam having supports at the ends and a load at the middle.

Single Throw Crank Under Torsion

In addition to the stresses resulting from the transmission of the torque during the normal functioning of a multi-cylinder engine, extreme conditions, such as would result from pre-ignition in the cylinder whose rod operates at that particular crank throw, should be provided for. This force produces only additional bending stress in the journals. In Fig. 1 F represents this maximum axial force at the point of maximum explosive pressure and the resultant when combined with the maximum force tangential to the crank radius is designated by F_1. It will be sufficiently accurate and well on the safe side to always consider that the axial force in this sense is acting at right angles to the tangential.

This method of treatment is particularly adaptable to multi-cylinder engines. In engines having cylinders numbering four or less it will be generally found that the greatest stresses result directly from the forces of explosion. In such cases the crankshaft need only to be treated as a beam whose greatest bending moment is caused by the maximum explosive force on the piston. Airplane engines rarely have less than four cylinders, so this analysis will apply in a majority of cases.

In all structures this is a special case but if the reader acquaints himself thoroughly with the action of a single throw crank under torsion it is an easy matter and at the same time equally correct to apply the same treatment to crankshafts having two or more crank throws between bearings. It must be remembered, however, that this action exemplifies uniformly stressed material. When certain sections of the shaft are for other reasons made overly strong they may be treated as being perfectly rigid.

Stresses in the Journals

The stresses due to torsion are distributed evenly throughout the length of the crankshaft journal, hence the weakest section is at the point of greatest bending moment. The greatest stress may be considered as due to the combined moments of torsion and bending at the points of support. The crankshaft should be treated as a simple beam with the supports in the plane of the main bearing bolts nearest the loaded crankpin, shown on the diagram as section BB.

There are two possible methods for treating such a beam, one having free ends and the other with ends rigidly supported. If the ends were free, the moment would be maximum at the crankpin in the plane of the application of the force and have a value of $\frac{Fa}{2}$ and the moment at the points of support would be zero. This condition could only be approached in a single cylinder engine whose bearings were relatively short in proportion to their diameter. Support the ends rigidly, the bending moment at both the crankpin and at the supports becomes $\frac{Fa}{4}$ and closely approximates the condition in a multi-cylinder engine having outboard bearings.

The following calculations, with reference to Fig. 1, will best show the methods employed in determining the diameters of the crankshaft journals. For example, the computations will be based on a single throw of a crankshaft between main bearings having bolts spaced 6 in. apart longitudinally. This will be on a twelve cylinder 60 degree V-type of 4½ x 6 in. engine running at a maximum speed of 2000 r.p.m.

The ratio of the maximum instantaneous to mean torque for such an arrangement of twelve cylinders is approximately 113 per cent. It will be assumed that the mean torque delivered from each cylinder of this engine is 79 lb. ft. at the maximum speed, giving a mean torque for the engine of 948 lb. ft. From these the maximum tangential force at the crank radius of 3 in. is easily determined.

$$F_1 = 948 \times 1.13 \times \frac{12}{3} = 4285 \text{ lb.}$$

The maximum torsional moment then becomes,

$$M_t = F_1 \times 3 = 4285 \times 3 = 12{,}855 \text{ lb.-in.}$$

To provide for extreme conditions, the force producing bending at BB will be resolved from the maximum tangential and the maximum axial forces. The latter, if assuming a maximum gas pressure of 450 lb. per sq. in. or a total of 7155 lb. and the weight of the reciprocating parts as 3 lb., becomes 5652 lb. Then,

$$F_b = \sqrt{F^2 + F_1^2} = 7100 \text{ lb}$$

$$M_b = \frac{F_b a}{4} = 5325 \text{ lb.-in}$$

The combined moments of bending and the torsion, giving an equivalent bending moment at the section, should be made as follows

$$M_b = \frac{1}{2} M_b + \frac{1}{2}\sqrt{M_b^2 + M_t^2} = 16{,}562 \text{ lb.-in.}$$

The required section modulus Z, using a steel having an elastic limit of 125 000 lb. per sq. in. and employing a safety factor of 8, becomes

$$Z = \frac{M_t}{s_b} = \frac{16{,}562}{15{,}625} = 1.06$$

For solid shaft,

$$Z = \frac{\pi D^3}{32} \text{ or } D = 2.16 \text{ in.}$$

For hollow shaft,

$$Z = \frac{\pi(D^4 - d^4)}{32D} \text{ or } d^4 = D^4 - 10.78D$$

When D = outside diameter
and d = inside diameter

The following sizes have been determined for purposes of comparison

$D = 2\frac{1}{4}''$, $d = 1.00''$, wall thickness = .58" area sq. in. 3.04
$D = 2\frac{3}{8}''$, $d = 1.57''$, wall thickness = .40" area sq. in. 2.50
$D = 2\frac{1}{2}''$, $d = 1.80''$, wall thickness = .32" area sq. in. 2.19

As the above method for determining the diameter of the journals takes into consideration both the bending and torsion with a reasonable factor of safety, it will be found in a majority of cases that the stress due to direct shear is well within the limits. Take, for example, the 2½ in. diameter journal with the smallest sectional area of 2.19 sq. in. The force F of 5652 lb. is producing direct shear in both journal sections. The unit shear stress becomes,

$$S_s = \frac{F}{2A} = \frac{5652}{2 \times 2.19} = 1290 \text{ lb. per sq. in.}$$

This shear stress will act on the remotest fibers of the section which is already in shear due to torsion. The latter can be determined as follows. The polar section modulus of a journal having an outside diameter of 2½ and an inside diameter of 1.80 in. becomes,

$$Z_p = \frac{\pi(D^4 - d^4)}{16D} = 2.12$$

$$S_1 = \frac{M_t}{Z_p} = \frac{12855}{2.12} = 6070 \text{ lb. per sq. in.}$$

The combined unit shear stress at the remotest fibers would then be the sum of the unit stress due to direct shear and that due to torsion. This equals 7360 lb. per sq. in. The corresponding elastic limit for shear of the material under consideration would be $\frac{4}{5}$ of 125,000 lb. per sq. in., the elastic limit for tension, or 100,000 lb. per sq. in.

$$\text{Factor of safety for shear} = \frac{100000}{7360} = 13.5$$

It is evident from the above factor that, in this case, the shear stress is within the limits.

Of the three outside diameters for hollow journals determined above, it will be noted that the largest diameter represents the smallest cross sectional area, and consequently the lightest weight for any given length. Obtaining the required section modulus with less metal, together with the stiffness to be had from large diameters, naturally leads the designer in this direction, but the limit is quickly approached. Excessive peripheral bearing velocity with high bearing load is not permissible. This is mainly a problem in bearing design, but should be carefully considered in conjunction with the crankshaft before finally determining the diameters of the journals.

Stresses in the Crankpins

The methods employed in determining the size of the main journals can be applied to the crankpins as well. The moment of torsion at section AA, as a result of the tangential force F_1, is the same as at section BB. The tangential force F_1, however, produces no bending strains at AA so to cover extreme cases regard need only be taken of F, the axial force, as applied to a beam having ends rigidly supported. The bending moment at section AA then becomes $M_b = \frac{F \times n}{4} = 4239$ lb.-in.

Combine the above moment of bending with the torsional moment M_t previously found to be 12,855 lb.-in., the equivalent bending moment becomes

$$M_b = \frac{1}{2} M_b + \frac{1}{2}\sqrt{M_b^2 + M_t^2} = 13{,}535 \text{ lb.-in.}$$

The required section modulus of the pin section therefore needs to be, in this particular case, only about 80 per cent of that required for the journal. The outside diameter of the crankpin is generally determined in the design of the necessary crankpin bearing. In such cases it is only required to provide an ample modulus of section with the diameter determined.

In a short beam, failure from shear usually occurs before that from bending. Section CC, shown in Fig. 1, as that section of the crankpin nearest the cheeks, may be regarded as at the supports of a short beam where failure is possible. It is therefore quite essential to carefully determine the combined stress of torsion and shear at this point, making sure that it does not exceed that which is allowable. The method employed is precisely the same as that given for determining similar stresses in the journals but the values obtained may be different as any appreciable reduction in the polar section modulus or the area of the section might introduce stresses in excess of safety.

Stresses in the Cheeks

Before computing the proper dimensions of the crank cheeks a simple analysis should be made to determine the proper shape. This is limited mainly by the space available in the design under consideration and also by the practical limits of manufacturing.

The cheeks must be somewhat wider than the crankpin and journal diameters in order to provide a shoulder for the bearings and when the cylinders are located as close together as possible the cheek thickness should not be less than the remaining distance between the ends of the crankpin bearings and the journals. Rectangular cheek sections are generally used as this shape is simple to manufacture.

The weight may be reduced considerably by drilling and removing corners with very little sacrifice to strength and it is advisable to do so when it can be accomplished without introducing difficult machine operations. The crankshaft cheeks may be tapered from the width necessary at the journals to a narrower width at the crankpins. Considerable weight is saved by this method without exceeding the allowable stress as the bending moment due to the tangential force F_1 is maximum at the journals and zero at the crankpin.

As an example for the following calculations it will be assumed that the crank cheeks are of rectangular section, 1 in. thick (b) and 3 in. wide (d), and that the sides are straight. The weakest section would then be nearest the journal, shown in Fig. 1 as section DD. The treatment which follows would apply equally as well to any section along the cheek if it were required to determine the degree of taper allowable.

The stresses due to direct shear and compression are comparatively small, therefore it is sufficiently accurate to treat section DD under the compound stress of torsion and bending only. The torsional moment on the crank cheek, about a neutral axis EE through the center, is a result of the tangential force F_1 acting on arm e, assumed for example to be 1.5 in.

$$M_t = F_1 \times e = 4285 \times 1.5 = 6427 \text{ lb. in}$$

The polar section modulus for cases of this kind may be safely taken as,

$$Z_p = \frac{2}{9} b^2 d = 667$$

The shear stress at the remotest fibers becomes

$$S_1 = \frac{M_t}{Z_p} = 9640 \text{ lb. per sq. in.}$$

The neutral axis in the case of bending is FF at right angles to EE. The bending moment is due to the tangential force F_1 acting on arm c assumed for example to be 1.75 in.

$$M_b = F_1 \times c = 4285 \times 1.75 = 7500 \text{ lb. in.}$$

The rectangular section modulus about the neutral axis FF becomes,

$$Z = \frac{bd^2}{6} = 1.5$$

The stress due to bending becomes

$$S_b = \frac{M_b}{Z} = 5000 \text{ lb. per sq. in.}$$

The equivalent shear stress may be found by combining the stresses due to torsion and bending as follows,

$$S = \sqrt{\frac{(S_b)^2}{2} + (S_1)^2} = 9950 \text{ lb. per sq. in.}$$

It is evident from the result that the dimensions assumed are ample, for the factor of safety, if employing a steel having

FIG. 2 SIMPLE EXAMPLES OF BALANCE

an elastic limit in shear of 100,000 lb. per sq. in., is slightly over 10. Owing to the complexity of the stresses in the crank cheeks, a factor of safety lower than 10 cannot be recommended.

It has been the practice of some manufacturers to grade the sizes of the cheek sections, beginning with the largest at the driving end. This appears to be useless economy as it is difficult to estimate the percentage of the total torque that is being transmitted by each cheek.

The theory that each cheek is transmitting the power of all cylinders which it precedes in the direction of the driving end is partly disproved by this treatment in that the stresses due to both bending and torsion are the same in corresponding sections on any given throw.

Torsional Vibration

All bodies have definite periods of vibration of their own. The frequency of these vibrations depends upon the shape of the body and the elasticity of its material. When the vibrations synchronize with the impulse period, the resonance effects may become very disagreeable. This is generally referred to in the case of crankshafts as the critical speeds. At speeds of pronounced torsional vibration the action of the shaft may be said to be that of winding up and unwinding. The deflections resulting from the torque variations of the engine are then in step with some multiple of the natural period of the shaft. At speeds above or below the critical point smoothness of running is resumed but if the speed is increased considerably, one or more additional critical periods may be reached, and at these as before, synchronization between the torque impulses and some multiple of the natural period of the shaft again takes place.

No matter how perfectly the engine is balanced some degree of torsional vibration is always present. Critical periods generally occur at a correspondingly lower speed in six-cylinder crankshafts due to their greater length and are also more noticeable in engines employing long strokes. It is advisable for the designer to guard against excessive torsional vibration. No practical means is known by which to calculate before hand at which speed the vibration will be of a critical nature as it is difficult to accurately determine the moment of inertia of the shaft. Much time and experimentation however can be saved by first designing the crankshaft as stiff as is rationally possible, in order to carry the period of resonance outside the range of running speeds.

For automobile engines the use of an extra flywheel on the front end and also vibration dampers have both been partially successful in reducing the vibration but the additional weight represented by these units would prohibit the application of

such methods on the lighter types of engines. The problems involved, however, in the case of the airplane engine, in some respects, are not so difficult to provide for. The maximum speeds are generally lower and the average speed range is narrower therefore it is only necessary to avoid torsional vibration within the given speed limits.

Balance

The addition of counterweights to the crankshaft as a means of obtaining rotary balance is mainly an element of engine design. The centrifugal force caused by the unbalanced rotating weights, namely, the crankpins, and cheeks, and some of the lower end of the connecting rod, is continuously acting radially from the center and produces bearing pressures of considerably magnitude. This is particularly true at high engine speeds. When the normal speed of the engine is moderate and there is ample room for bearings in the design, the advantages to be had by the addition of counterbalances is greatly offset by the sacrifice involved in increasing the total weight of the engine. If considered purely from the weight standpoint, it becomes a question of determining which is the lighter, counterbalances or the necessary bearing area, with the subsequent addition of stiffness to the crankcase, to withstand these pressures. This naturally should be studied individually for each type of crankshaft that is being designed.

Another important phase in connection with balancing the crankshaft is that the addition of counterbalances leads to an increase of torsional vibration. Provision must then be made for a stiffer crankshaft and this invariably results in further increase in weight.

The dynamic balance of the crankshaft is a very interesting subject but altogether too extensive to be treated with any degree of completeness here. The reader should become familiar however with the fundamentals of rotary balance. Unbalanced rotating masses are one of the principal causes of vibration. When no special means is provided for balancing the crankshaft, a simple analysis should be made for the purpose of incorporating in the design the necessary rigidity in order that the vibrations shall not attain serious or unpleasant dimensions.

There may exist with rotating masses three conditions of balance. These are generally known as static, running and distortion balance, simple examples of which are shown by diagrams. All crankshafts should have static balance, that is, the center of the entire mass located upon the rotating axis of the shaft. A shaft may be in static balance and not in running or distortion balance but the latter two forms of balance cannot exist without the masses being first in balance statically as they are in reality only special cases of the former.

The arrows in Fig. 2 denote the direction of the centrifugal couple of a shaft which is only in static balance. The axis of the couple is rotating in a plane at right angles to the axis of the shaft and the same angular velocity. The magnitude of the couple is constant, but due to its rotating axis, varies in direction. Couples of this nature produce additional pressure on the bearings. Take for example an ordinary four-cylinder three-bearing crankshaft having cranks 180 deg. apart. It is evident that the center bearing in this case must resist the additional pressure of two centrifugal couples and the crank case as well must be substantially rigid at this point in order to prevent severe distortions and possible fractures from occurring.

Running balance exists when all of the centrifugal couples of a statically balanced shaft neutralize each other. This is accomplished by locating the rotating masses so that the couples set up about the axis are equal in magnitude and opposite in direction. If individual masses are employed they must be located diametrically opposite the unbalanced mass and each must have equal moments about the axis. In the case of three or more balancing masses a graphical representation would appear as a closed polygon. If it is necessary to locate these masses in other planes they should be located in respect to a given reference plane so that the sum of the products, of the distances to, and the forces in each plane, shall equal zero or in other words the graphical representation is a closed polygon.

Distortion balance, as a special case of both static and running balance, is present only when all of the masses are in balance in each plane of rotation. Owing to the presence of the crankpin, distortion balance can never be complete in an actual crankshaft.

Large Curtiss Deal

Announcement has been made jointly by the War Department and W. W. Mountain, vice-president and general manager of the Curtiss Aeroplane and Motor Corp. that the deal for the purchase of airplanes and motors from the government by the Curtiss Co. has been consummated.

The contract, closing the deal, was signed for the War Department by Maj. Gen. Charles T. Menoher, Director of Air Service, and C. M. Keyes, vice president of the Curtiss Aeroplane and Motor Corp.

By its terms, the Curtiss Company will receive 2,176 airplanes and 4,608 motors.

The majority of planes are the Curtiss JN type, used almost exclusively by the air service in training U. S. pilots during the war. They were manufactured for the government by Curtiss plants at Buffalo, Hammondsport and Garden City. The motors are the well-known Curtiss OX-5 type.

The machines and motors were examined and inventoried at the thirty-two fields which were maintained by the government by representatives from the War Department and the Curtiss Co.

It is the intention of the Curtiss corporation to concentrate the purchased planes and motors at five fields and to maintain at those points a staff of expert mechanics to inspect every plane before delivery to customers and to send all planes requiring overhauling to their plants at Buffalo where whatever is necessary to put them in first-class condition according to Curtiss standards will be done.

The deal involves the largest single purchase of airplane material ever made by a private corporation and is in line with the policy adopted by the government to encourage the airplane industry and also to take every precaution against accident through unorganized distribution.

Atlantic to Pacific Flight

A transcontinental flight from New York to San Francisco will shortly be undertaken by a Martin bomber equipped with two Liberty-12 engines. According to the plans, recently completed, the total flight distance has been computed as 3,750 miles, which is to intended will be covered in two successive days. Only one stop is contemplated en route, this will be at North Platte, Neb., giving a first leg of 1,502 miles, and a second and final leg of 1,248 miles.

Capt. Roy N. Francis, A. S., and Lieut. Edmund A. Clune, A. S., have been designated as pilots and will be assisted by two or three mechanics.

The condition of the territory passed over will be tabulated from the standpoint of good and bad terrain for aerial routes, and valuable information as to meteorological conditions will be gained. The reliability and the durability of the Liberty engines will also be tested.

The last trans-continental flight made by the Air Service was that of Major Theo. C. Macauley, who doubled the southern continental route from San Diego, Cal., to Jacksonville, Fla., between April 12 and 18, a distance of 4,642 miles in 2655 minutes flying time. He made several stops en route. His eastern flight, with the benefit of a western wind, was made in 19 hr. and 15 min. flying time. He used a DH-4A plane with a Liberty engine.

Aero Show at Amsterdam

An aircraft exposition is to be held during the month of August, 1919, at Amsterdam, under the auspices of the Chambers of Commerce of Amsterdam and Rotterdam, and with the sanction of the Netherlands government.

This will be the first aircraft exposition to be held in Holland. In view of the interest Holland displays in establishing aerial commercial services with her neighbors and her vast colonial domain in the Far East, it is expected that the announced aero show will greatly stimulate the starting of aerial transport lines.

Numerous manufacturers of the principal Allied countries have already announced their participation and indications are at hand showing that American manufacturers will also be well represented. The representative of the exposition in this country is J. C. Ankersmit, 17 Battery Place, New York.

Nomenclature for Aeronautics

The National Advisory Committee for Aeronautics has just issued a preprint of Report No. 25 of its fourth annual report which contains the Nomenclature for Aeronautics adopted by the committee at its annual meeting, Oct. 10, 1918.

Report No. 25, which supersedes Report No. 15 of the third annual report (1917), differs from the latter by the substitution of the terms *airship* for *dirigible*, and *fuselage* for *airplane body*, and the definition of the following newly added terms: attitude, angle of bank, ceiling, crosswind force, droop, hull of an airship, lift of an airship, loop, maroufiage, overhang, pancake, pitch of a propeller, angle of pitch, plane, pressure nozzle, rate of climb, right-hand engine, righting moment, roll, rudder bar, speed (air and ground), spin, tandem (planes), Venturi tube, wash in, zero lift line.

The new Nomenclature for Aeronautics, which answers the purpose to help securing uniformity in the official documents of the government as well as in the technical journals, is reprinted herewith in full.

AEROFOIL. A wing-like structure, flat or curved, designed to obtain reaction upon its surfaces from the air through which it moves.

AEROFOIL SECTION. A section of an aerofoil made by a plane parallel to the plane of symmetry of the aerofoil.

AEROPLANE. See Airplane.

AILERON. A movable auxiliary surface, usually part of the trailing edge of a wing, the function of which is to control the lateral attitude of an airplane by rotating it about its longitudinal axis.

AIRCRAFT. Any form of craft designed for the navigation of the air—airplanes, airships, balloons, helicopters, kites, kite balloons, ornithopters, gliders, etc.

AIRPLANE. A form of aircraft heavier than air which has wing surfaces for support in the air, with stabilizing surfaces, rudders for steering, and power plant for propulsion through the air. This term is commonly used in a more restricted sense to refer to airplanes fitted with landing gear suited to operation from the land. If the landing gear is suited to operation from the water, the term "seaplane" is used. (See definition.)

Pusher.—A type of airplane with the propeller in the rear of the engine.

Tractor.—A type of airplane with the propeller in front of the engine.

AIRSHIP. A form of balloon, the outer envelope of which is of elongated form, provided with a propelling system, car, rudders, and stabilizing surfaces.

Nonrigid.—An airship whose form is maintained by the pressure of the contained gas assisted by the car suspension system.

Rigid.—An airship whose form is maintained by a rigid structure contained within the envelope.

Semirigid.—An airship whose form is maintained by means of a rigid keel and by gas pressure.

AIR-SPEED METER. An instrument designed to measure the speed of an aircraft with reference to the air.

ALTIMETER. An aneroid mounted on an aircraft to indicate continuously its height above the surface of the earth. Its dial is marked in feet, yards, or meters.

ANEMOMETER. Any instrument for measuring the velocity of the wind.

ANGLE. *Of attack* (or *of incidence*) *of an aerofoil.*—The acute angle between the direction of the relative wind and the chord of an aerofoil, i. e., the angle between the chord of an aerofoil and its motion relative to the air. (This definition may be extended to any body having an axis.)

Critical.—The angle of attack at which the lift-curve has its first maximum, sometimes referred to as the "burble point."

Gliding.—The angle the flight path makes with the horizontal when descending in still air under the influence of gravity alone, i. e., without power from the engine.

ANGLE OF INCIDENCE (*in directions for rigging*). In the process of rigging an airplane some arbitrary definite line in the airplane is kept horizontal, the angle of incidence of a wing, or of any aerofoil, is the angle between its chord and this horizontal line, which usually is the line of the upper longitudinals of the fuselage or nacelle.

APPENDIX. The hose at the bottom of a balloon used for inflation. In the case of a spherical balloon it also serves for equalization of pressure.

ASPECT RATIO. The ratio of span to chord of an aerofoil.

ATTITUDE. The attitude of an aircraft is determined by the inclination of its axes to the "frame of reference"; e. g., the earth, or the relative wind.

AVIATOR. The operator or pilot of heavier-than-air craft. This term is applied regardless of the sex of the operator.

AXES OF AN AIRCRAFT. Three fixed lines of reference, usually centroidal and mutually rectangular.

The principal longitudinal axis in the plane of symmetry, usually parallel to the axis of the propeller, is called the *longitudinal* axis, the axis perpendicular to this in the plane of symmetry is called the *normal* axis, and the third axis, perpendicular to the other two, is called the *lateral* axis. In mathematical discussions the first of these axes, drawn from front to rear, is called the X axis, the second, drawn upward, the Z axis, and the third, running from right to left, the Y axis.

BALANCING FLAPS. See Aileron.

BALLONET. A small balloon within the interior of a balloon or airship for the purpose of controlling the ascent or descent and for maintaining pressure on the outer envelope so as to prevent deformation. The ballonet is kept inflated with air at the required pressure, under the control of valves by a blower or by the action of the wind caught in an air-scoop.

BALLOON. A form of aircraft comprising a gas bag, rigging and a basket. The support in the air results from the buoyancy of the air displaced by the gas bag, the form of which is maintained by the pressure of a contained gas lighter than air.

Barrage.—A small spherical captive balloon, raised as a protection against attacks by airplanes.

Captive.—A balloon restrained from free flight by means of a cable attaching it to the earth.

Kite.—An elongated form of captive balloon, fitted with tail appendages to keep it headed into the wind, and deriving increased lift due to its axis being inclined to the wind.

Pilot.—A small spherical balloon sent up to show the direction of the wind.

Sounding.—A small spherical balloon sent aloft without passengers but with registering meteorological instruments.

BALLOON BED. A mooring place on the ground for a captive balloon.

BALLOON CLOTH. The cloth, usually cotton, of which balloon fabrics are made.

BALLOON FABRIC. The finished material, usually rubberized, of which balloon envelopes are made.

BANK. To incline an airplane laterally—i. e., to roll it about the longitudinal axis. Right bank is to incline the airplane with the right wing down. Also used as a noun to describe the position of an airplane when its lateral axis is inclined to the horizontal.

BANK, ANGLE OF. The angle through which an aircraft must be rotated about its longitudinal axis in order to bring its lateral axis into the horizontal plane.

BAROGRAPH. An instrument used to record variations in barometric pressure. In aeronautics the charts on which the records are made indicate altitudes directly instead of barometric pressures.

BASKET. The car suspended beneath a balloon, for passengers, ballast, etc.

BIPLANE. A form of airplane in which the main supporting surface is divided into two parts, one above the other.

BODY OF AN AIRPLANE. See Fuselage and Nacelle.

BONNET. The appliance, having the form of a parasol, which protects the valve of a spherical balloon against rain.

BRIDLE. The system of attachment of cable to a balloon, including lines to the suspension band.

BULL'S-EYES. Small rings of wood, metal, etc., forming part of balloon rigging, used for connection or adjustment of ropes.

BUBBLE POINT See Angle, critical

CABANE A pyramidal framework upon the wing of an airplane, to which stays, etc., are secured

CAMBER The convexity or rise of the curve of an aerofoil from its chord, usually expressed as the ratio of the maximum departure of the curve from the chord to the length of the chord "Top camber" refers to the top surface of an aerofoil, and "bottom camber" to the bottom surface, "mean camber" is the mean of these two

CAPACITY. See Load The cubic contents of a balloon.

CEILING *Service*—The height above sea level at which a given aircraft ceases to rise at a rate higher than a small specified one, say 100 feet per minute. This specified rate may be different in the services of different countries

Absolute—The maximum height above sea level to which a given aircraft can rise

Theoretical—The limiting height to which a given aircraft can rise determined by computations of performance, based upon the drawings and wind tunnel data.

CENTER OF PRESSURE OF AN AEROFOIL The point in the plane of the chords of an aerofoil, prolonged if necessary, through which at any given attitude the line of action of the resultant air force passes. (This definition may be extended to any body)

CHORD OF AN AEROFOIL SECTION. *For theoretical purposes*—The zero lift line, i. e., the limiting position, in the section, of the line of action of the resultant air force when the position of the section is such that the lift is zero

Practical.—The line of a straight edge brought into contact with the lower surface of the section at points near its edges. In the case of an aerofoil having double convex camber, the straight line joining the entering and trailing edges.

Length.—The length of the chord is the length of the projection of the aerofoil section on its chord

CLINOMETER: See Inclinometer.

CONCENTRATION RING A hoop to which are attached the ropes suspending the basket of a spherical balloon

CONTROLS. A general term applying to the means provided for the operating devices used to control speed, direction of flight, and attitude of an aircraft.

CONTROL COLUMN: The vertical lever by means of which certain of the principal controls are operated, usually those for pitching and rolling

CROSS-WIND FORCE The component perpendicular to the lift and to the drag of the total force on an aircraft due to the air through which it moves.

CROW'S-FOOT. A system of diverging short ropes for distributing the pull of a single rope

DECALAGE: The angle between the chords of the principal and tail planes of a monoplane The same term may be applied to the corresponding angle between the direction of the chord or chords of a biplane and the direction of a tail plane (This angle is also sometimes known as the longitudinal V of the two planes.)

DIHEDRAL IN AN AIRPLANE The angle included at the intersection of the imaginary surfaces containing the chords of the right and left planes (continued to the plane of symmetry if necessary) This angle is measured in a plane perpendicular to that intersection The measure of the dihedral is taken as 90° minus one-half of this angle as defined

The dihedral of the upper planes may and frequently does differ from that of the lower planes in a biplane

DIRIGIBLE See Airship

DIVING RUDDERS See Elevator

DOPE A general term applied to the material used in treating the cloth surface of airplane members and balloons to increase strength, produce tautness, and act as a filler to maintain airtightness it usually has a cellulose base

DRAG The component parallel to the relative wind of the total force on an aerofoil or aircraft due to the air through which it moves.

In the case of an airplane, that part of the drag due to the wings is called "wing resistance"; that due to the rest of the airplane is called "parasite resistance."

DRIFT See Drag Also used as synonymous with "leeway," q. v.

DRIFT METER An instrument for the measurement of the angular deviation of an aircraft from a set course, due to cross winds.

DRIP CLOTH: A curtain around the equator of a balloon, which prevents rain from dripping into the basket

DROOP: A permanent warp of an aerofoil such that the angle of attack increases toward the wing tips. (The opposite of "wash out")

ELEVATOR A movable auxiliary surface, usually attached to the tail, the function of which is to control the longitudinal attitude of an aircraft by rotating it about its lateral axis.

EMPENNAGE The tail surfaces of an aircraft Sometimes the word is limited to the fixed stabilizing portion of the tail—usually comprising the tail plane and vertical fin, to which are attached the elevator and rudders.

ENTERING EDGE The foremost edge of an aerofoil or propellor blade

ENVELOPE The outer covering of a rigid airship, or, in the case of a balloon or a nonrigid airship, the gas bag which contains the gas

EQUATOR The largest horizontal circle of a spherical balloon.

FINS: Small fixed aerofoils attached to different parts of aircraft, in order to promote stability, for example, tail fins, skid fins, etc Fins are often adjustable They may be either horizontal or vertical

FLIGHT PATH: The path of the center of gravity of an aircraft with reference to the earth

FLOAT That portion of the landing gear of an aircraft which provides buoyancy when it is resting on the surface of the water

FUSELAGE: The elongated structure to which are attached the landing gear, wings and tail A fuselage is rarely used with pushers, and in general it is designed to hold the passengers

GAP The shortest distance between the planes of the chords of the upper and lower planes of a biplane, measured along a line perpendicular to the chord of the lower plane at its entering edge

GAS BAG See Envelope.

GLIDE. To fly without engine power

GLIDER. A form of aircraft similar to an airplane, but without any power plant

When utilized in variable winds it makes use of the soaring principles of flight and is sometimes called a soaring machine

GLIDING ANGLE See Angle, gliding

GORE: One of the segments of fabric composing the envelope

GROUND CLOTH Canvas placed on the ground to protect a balloon

GUIDE ROPE: The long trailing rope attached to a spherical balloon or airship, to serve as a brake and as a variable ballast.

GUY A rope, chain, wire or rod attached to an object to guide or steady it, such as guys to wing, tail, or landing gear

HANGAR A shed for housing airships or airplanes

HELICOPTER: A form of aircraft whose support in the air is derived from the vertical thrust of propellers

HORN A short arm fastened to a movable part of an airplane, serving as a lever arm, e. g., aileron horn, rudder horn, elevator horn

HULL OF AN AIRSHIP The main structure of a rigid airship, consisting of a covered elongated framework which incloses the gas bags and which supports the nacelles and equipment

INCLINOMETER: An instrument for measuring the angle made by any axis of an aircraft with the horizontal, often called a clinometer

INSPECTION WINDOW A small transparent window in the envelope of a balloon or in the wing of an airplane to allow inspection of the interior

KITE A form of aircraft without other propelling means than the towline pull, whose support is derived from the force of the wind moving past its surface

LANDING GEAR: The understructure of an aircraft designed to carry the load when resting on or running on the surface of the land or water

LEADING EDGE: See Entering edge

LEEWAY The angular deviation from a set course over the earth, due to cross currents of wind, also called drift; hence, "drift meter"

LIFT: The component of the total force due to the air resolved perpendicular to the relative wind and in the plane of symmetry.

LIFT OF AN AIRSHIP: *Dynamic*—The component of the total force on an airship due to the air through which it moves, resolved perpendicular to the relative wind and in the plane including the direction of the relative wind and the longitudinal axis.

Static—The vertical upward force on an airship when at rest in the air, due to buoyancy

LIFT BRACING See Stay.

LOAD: *Dead.*—The structure, power plant, and essential accessories of an aircraft Including in this are the water in the radiator, tachometer, thermometer, gauges, air-speed indicator, levels, altimeter, compass, watch, and hand starter.

Full.—The total weight of an aircraft when loaded to the maximum authorized loading of that particular type.

Useful—The excess of the full load over the dead-weight of the aircraft itself Therefore useful load includes the crew and passengers, oil and fuel, electric-light installation, chart, board, gun mounts, bomb storage and releasing gear, wireless apparatus, etc

LOADING See Wing loading

LOBES: Bags at the stern of an elongated balloon designed to give it directional stability.

LONGERON: See Longitudinal.

LONGITUDINAL A fore-and-aft member of the framing of an airplane body or of the floats, usually continuous across a number of points of support

LOOP, A. An aerial maneuver in which the airplane describes an approximately circular path in the plane of the longitudinal and normal axes, the lateral axis remaining horizontal, and the upper side of the airplane remaining on the inside of the circle

MAROUFLAGE The process of wrapping and winding wooden parts in cloth.

MONOPLANE: A form of airplane which has but one main supporting surface extending equally on each side of the body

MOORING BAND. The band of tape over the top of a balloon to which are attached the mooring ropes

NACELLE The inclosed shelter for passengers or for an engine Usually in the case of a single-engine pusher it is the central structure to which the wings and landing gear are attached

NET: A rigging made of ropes and twine on spherical balloons which supports the entire load carried

ORNITHOPTER: A form of aircraft deriving its support and propelling force from flapping wings

OVERHANG: One-half the difference in the span of the upper and lower planes of a biplane

PANCAKE To "level off" an airplane, just before landing, at too great an altitude, thus stalling it and causing it to descend with the wings at a very large angle of incidence

PANEL The unit piece of fabric of which the envelope is made

PARACHUTE: An apparatus, made like an umbrella, used to retard the descent of a falling body.

PATCH SYSTEM A system of construction in which patches (or adhesive flaps) are used in place of the suspension band.

PERMEABILITY: The measure of the loss of gas by diffusion through the intact balloon fabric

PITCH OF A PROPELLER. (a) *Pitch, effective*—The distance an aircraft advances along its flight path for one revolution of of the propeller

(b) *Pitch, geometrical.*—The distance an element of a propeller would advance in one revolution if it were turning in a solid nut—i. e., if it were moving along a helix of slope equal to the angle between the chord of the element and a plane perpendicular to the propeller axis. The mean geometrical pitch of a propeller, which is a quantity commonly used in specifications, is the mean of the geometrical pitches of the several elements.

(c) *Pitch, virtual*—The distance a propeller would have to advance in one revolution in order that there might be no thrust

(d) *Pitch speed.*—The product of the mean geometrical pitch by the number of revolutions of the propeller in unit time—i. e., the speed the aircraft would make if there were no slip

(e) *Slip*—The difference between the effective pitch and the mean geometrical pitch Slip is usually expressed as a percentage of the mean geometrical pitch.

PITCH, ANGLE OF The angle between two planes, defined as follows: One plane includes the lateral axis of the aircraft and the direction of the relative wind, the other plane includes the lateral axis and the longitudinal axis. (In horizontal normal flight this angle of pitch is, then, the angle between the longitudinal axis and the direction of the relative wind)

PITOT TUBE A tube with an end open square to the fluid stream, used as a detector of an impact pressure. It is usually associated with a coaxial tube surrounding it, having perforations normal to the axis for indicating static pressure, or there is such a tube placed near it and parallel to it, with a closed conical end and having perforations in its side. The velocity of the fluid can be determined from the difference between the impact pressure and the static pressure, as read by a suitable gauge. This instrument is often used to determine the velocity of an aircraft through the air.

PLANE. One of the main supporting surfaces of an airplane or of a wing. (Thus the upper or lower plane of an airplane or the upper right plane or lower right plane of the right wing.)

PONTOONS See Float.

PRESSURE NOZZLE The apparatus which, in combination with a gauge, is used to measure speed through the air.

PUSHER See Airplane.

PYLON A mast or pillar serving as a marker of a course.

RACE OF A PROPELLER. See Slip stream

RATE OF CLIMB The vertical component of the flight speed of an aircraft—i. e., its vertical velocity with reference to the air.

RELATIVE WIND. The motion of the air with reference to a moving body. Its direction and velocity, therefore, are found by adding two vectors, one being the velocity of the air with reference to the earth, the other being equal and opposite to the velocity of the body with reference to the earth.

RIGHT-HAND ENGINE. An engine designed to drive a right-hand tractor screw

RIGHTING MOMENT A moment which tends to restore an aircraft to its previous attitude after any rotational disturbance.

RIP CORD. The rope running from the rip panel of a balloon to the basket, the pulling of which causes immediate deflation.

RIP PANEL A strip in the upper part of a balloon which is torn off when immediate deflation is desired.

ROLL, A. An aerial maneuver in which a complete revolution about the longitudinal axis is made, the direction of flight being maintained.

RUDDER: A hinged or pivoted surface, usually more or less flat or stream lined, used for the purpose of controlling the attitude of an aircraft about its normal axis—i. e., for controlling its lateral movement

Balanced.—A rudder having part of its surface in front of its pivot.

RUDDER BAR: The foot bar by means of which the rudder is operated.

SEAPLANE: A particular form of airplane in which the landing gear is suited to operation from the water.

(a) *Boat seaplane* (or *flying boat*)—A form of seaplane having for its central portion a boat which provides flotation It is often provided with auxiliary floats or pontoons.

(b) *Float seaplane*—A form of seaplane in which the landing gear consists of one or more floats or pontoons

SERPENT A short, heavy guide rope

SIDE SLIPPING Sliding downward and inward when making a turn, due to excessive banking. It is the opposite of skidding

SKIDDING Sliding sideways away from the center of the turn in flight. It is usually caused by insufficient banking in a turn and is the opposite of side slipping

SKIDS: Long wooden or metal runners designed to prevent nosing of a land machine when landing or to prevent dropping into holes or ditches in rough ground Generally designed to function should the landing gear collapse or fail to act.

SLIP STREAM (or *propeller race*) The stream of air driven aft by the propeller and with a velocity relative to the airplane greater than that of the surrounding body of still air

SOARING MACHINE See Glider

SPAN (or *spread*) The maximum distance laterally from tip to tip of an airplane or the lateral dimension of an aerofoil

SPEED *Air*—The speed of an aircraft relative to the air

Ground.—The horizontal component of the velocity of an aircraft relative to the earth.

SPIN An aerial maneuver consisting of a combination of roll and yaw, with the longitudinal axis of the airplane inclined steeply downward The machine descends in a helix of

large pitch and very small radius, the upper side of the machine being on the inside of the helix, and the angle of attack being maintained at a large value

STABILITY A body in any attitude has stability about an axis if, after a slight displacement about that axis, it tends to regain its initial attitude.

Directional.—Stability with reference to the normal axis

Dynamical—The quality of an aircraft in flight which causes it to return to a condition of equilibrium after its attitude has been changed by meeting some disturbance—e g, a gust This return to equilibrium is due to two factors First, the inherent righting moments of the structure, second, the damping of the oscillations by the tail, etc

Inherent—Stability of an aircraft due to the disposition and arrangement of its fixed parts, i e, that property which causes it to return to its normal attitude of flight without the use of the controls

Lateral—Stability with reference to displacements involving rolling or yawing, i e., displacements in which the plane of symmetry of the airplane is rotated.

Longitudinal.—Stability with reference to displacements involving pitching, i e, displacements in which the plane of symmetry of the airplane is not rotated.

Statical—In wind tunnel experiments it is found that there is a definite angle of attack, such that, for a greater angle or a less one, the righting moments are in such a sense as to tend to make the attitude return to this angle This holds true for a certain range of angles on each side of this definite angle, and the machine is said to possess "statical stability" through this range

A machine possesses statical stability if, when its attitude is disturbed, moments tending to restore it to this attitude are set up by the action of the air on the machine e g, if an aircraft, after initial disturbance, oscillates with swings of constantly increasing amplitude, it is statically stable but not dynamically stable

STABILIZER A fixed horizontal, or nearly horizontal, tail surface, used to steady the longitudinal motion and to damp oscillations in pitch

Mechanical—A mechanical device to steady the motion of an aircraft

STAGGER The amount of advance of the entering edge of the upper plane of a biplane over that of the lower, expressed as percentage of gap, it is considered positive when the upper surface is forward and is measured from the entering edge of the upper plane along its chord to the point of intersection of this chord with a line drawn perpendicular to the chord of the lower plane at its entering edge, all lines being drawn in a plane parallel to the plane of symmetry

(In directions for rigging)—The horizontal distance between the entering edge of the upper plane and that of the lower when the airplane is in the standard position, i e, when the arbitrary line of reference in the airplane is horizontal This line is usually the axis of the propeller shaft

STALLING A term describing the condition of an airplane which from any cause has lost the relative speed necessary for control.

STATOSCOPE An instrument to detect the existence of a small rate of ascent or descent, principally used in ballooning

STAY A wire, rope, or the like, used as a tie piece to hold parts together, or to contribute stiffness For example, the stays of the wing and body trussing

STEP A break in the form of the bottom of a float.

STREAM-LINE FLOW The condition of continuous flow of a fluid, as distinguished from eddying flow

STREAM-LINE SHAPE A shape intended to avoid eddying and to preserve stream-line flow

STRUT A compression member of a truss frame For instance, the vertical members of the wing truss of a biplane

SUSPENSION BAND The band around a balloon to which are attached the basket and the main bridle suspensions.

SUSPENSION BAR The bar used for the concentration of basket suspension ropes in captive balloons.

SWEEP BACK The horizontal angle between the lateral axis of an airplane and the entering edge of the main planes

TAIL The rear portion of an aircraft, to which are usually attached rudders, elevators, stabilizers, and fins.

TAIL CUPS The steadying device attached at the rear of elongated captive balloons.

TANDEM An airplane whose sets of planes are placed one in front of the other

TRACTOR See Airplane

TRAILING EDGE The rearmost edge of an aerofoil or propeller blade

TRIPLANE A form of airplane whose main supporting surface is divided into three parts, superimposed

TRUSS The framing by which the wing loads are transmitted to the body, comprises struts, stays, and spars.

UNDERCARRIAGE See Landing gear

VENTURI TUBE A short tube, flaring at the front end, and constricted approximately midway of its length, so that, when fluid flows through it, there will be a suction produced in a side-tube opening into the constricted throat This tube, when combined with a Pitot tube or with one giving static pressure, forms a pressure nozzle, which may be used as an instrument to determine the speed of an aircraft through the air

WARP To change the form of the wing by twisting it

WASH IN See Droop

WASHOUT A permanent warp of an aerofoil such that the angle of attack decreases toward the wing tips

WEIGHT, GROSS See Load, full

WING The aggregate sustaining structure on the right or left side of an airplane, comprising both planes and trussing (Thus, "detachable wings" and "folding wings.")

WING FLAP See Aileron.

WING LOADING The weight carried per unit area of supporting surface.

WING MAST The mast structure projecting above the wing, to which the top load wires are attached

WING RIB A fore-and-aft member of the wing structure used to support the covering and to give the wing section its form

WING SPAR OR WING BEAM A transverse member of the wing structure

YAW *Yawing*—Angular motion about the normal axis

Angle of—The angle between the direction of the relative wind and the plane of symmetry of an aircraft

ZERO LIFT LINE The limiting position in an aerofoil section of the line of action of the resultant air force when the position of the section is such that the lift is zero

Airship Lands on Hotel Roof

For the first time in the history of American aeronautics, an aircraft landed on the top of a building on May 23, when the United States Army airship A-4 alighted on the roof of a hotel in Cleveland After seven attempts the airship came to a stop on a specially constructed platform, 30 x 30 ft, and landed two of her passengers, after which she returned to Wingfoot Lake naval air station, near Akron, whence she had come

The A-4, which was built by the Goodyear Tire and Rubber Co, is 160 ft long and has a capacity of 95,600 cu ft the power plant consists of a 90 hp Curtiss OX-5 engine, driving a pusher propeller During this trip the airship was piloted by James Shade, test pilot for the Goodyear Co, Ralph H Upson, aeronautical engineer of the firm, and Maj C H Maranville, flying instructor at the training station, were among the passengers.

Book Review

ALL ABOUT AIRCRAFT By C J Blackburn and E J Newlin (Published by Simpkin, Marshall, Hamilton, Kent & Co London 122 pages Many illustrations)

This book is written in extremely simple style and in a most thorough and painstaking manner The illustrations—simple line drawings—are good and clear The little book gives a very fair idea of practical flight in the air with descriptions of various stunts and a very clear elementary description of guns and gun mounting A comprehensive survey is included of all the best known machines, each machine being illustrated with a cut Many types are covered The book should be of interest to every one who has anything to do with the military aspect of aeronautics

Lighter-than-Air Craft*

By Lieut.-Col. T R Cave-Browne-Cave

An airship derives her lift from the difference between the weight of the structure and all parts of the airship and the upward force on the airship, which is equal to the air which she displaces. The majority of this displacement is that due to the part of the ship which is filled with gas.

The variation in lift of the ship will, therefore, depend primarily upon the volume of gas in her envelope and upon the density of the surrounding air

As the ship increases her height from the ground the density of the surrounding air decreases, and owing to the decrease of pressure the hydrogen contained in the gas space will expand at a corresponding rate, so that, other things being equal, the available lift of the ship will remain the same. This process will continue until a height is reached at which the air has been totally expelled from the air chambers, and further expansion of the gas necessarily results in the discharge of some gas from the relief valves in the envelope Any further rise will, therefore, produce a decrease in the lifting power of the ship

Alteration of atmospheric temperature is usually accompanied by a corresponding alteration of temperature of the gas, and, providing the two temperatures remain the same, there will be no effect on the lift so long as gas is not discharged from the envelope

Variations in barometric pressure, that is, density of the atmosphere, affect both the density of the air and the density of the hydrogen, and a ship which is full of gas will, therefore, have considerably greater lift on a day when the barometer is high. This indicates that the lift of a ship may be expected to be good during cold weather with a high barometer Summarizing this in symbols

Lift $= V(P_a - P_g)$, where V = volume of gas space, P_g = density of gas, P_a = density of air displaced

An important variation in lift is caused when the airship is exposed to the heat of the sun and the temperature of the gas inside the envelope becomes higher than the temperature of the surrounding air The extent of this difference of temperature will vary with the strength of the sun, and also with the rate at which the surface of the envelope is being cooled by the passage of air over it This difference under certain circumstances may be very large and may vary rapidly Instances have been recorded in which there has been a difference of over 30 deg Fahr between the gas and air temperatures The gas temperature reckoned on the absolute scale was then 6 per cent higher than that of the atmosphere, and a "false lift" of 6 per cent of the total displacement of the ship was therefore produced

The reduction of lift caused by rain falling on an airship is comparatively small provided the surface of the envelope is made water proof Snow will not in general stick to the surface of an envelope, but in the event of melting snow sufficiently wet to stick to the surface, and possibly later to freeze onto it, considerable increase of weight might very rapidly be acquired There has been considerable experience of ships meeting snow while in flight, and as far as is known no serious trouble has actually been experienced due to snow sticking to the surface of the envelope.

Distribution of Weight and Rigidity of Envelope

The problem of suspending a weight from the lightest possible gas container is one which involves careful consideration of the ordinary principles used in calculating the distribution of loads and bending moment in ships and similar structures. The rigidity of the gas container may be provided in various ways The simplest is to make it solely of a perfectly flexible fabric, with no rigid stiffening whatever Such an envelope is referred to as a non-rigid It is kept distended to its correct shape by the internal pressure, which is maintained slightly in excess of the pressure outside Fabric may be regarded as capable of resisting tension and a considerable amount of shear, but it is, of course, incapable of resisting compression A single concentrated load suspended below the envelope will tend to produce compression in the underside of the envelope, partly by reason of the inward pull of the riggings, some of which must necessarily be inclined from the vertical, and also by any bending moment due to any lack of uniformity of distribution of load over the length of the envelope. The internal gas pressure produces a longitudinal tension in the fabric If the compression due to the riggings exceeds the tension due to the internal pressure, the envelope will deform

An alternative method of maintaining the shape of the gas container is to form the hull of the ship as a rigid structure of sufficient stiffness to maintain its own shape independent of any internal gas pressure The forces tending to deform this structure will depend upon the distribution of loads and upon

U S NAVAL AIRSHIP C-1—A NON-RIGID OF 180,000 CU. FT, 300 HP, AND 60 M P H

the distribution of gas inside the hull. Ships constructed on this system are described as rigids.

Intermediate between these two main types there is one referred to as the semi rigid This class is provided with a rigid keel of sufficient strength to maintain its rigidity under the action of the various loads of the ship The keel is carried by the envelope which contains the gas, but unlike the rigid the envelope is dependent for its shape upon the excess of internal pressure There is yet another type, one which is extensively used in Italian airship construction, in which the keel is not capable of taking a bending moment, but is capable of taking longitudinal compression when held straight by the main envelope.

Of these various types of construction it may generally be said that for small ships the non-rigid arrangement is entirely satisfactory, as the envelope is amply capable of providing sufficient rigidity with reasonably small internal pressure. For very large ships it becomes necessary to divide the gas chamber into a number of compartments for a reason which will be explained later, and also the large diameter would render the tension in fabric caused by the necessary excess of internal pressure very considerable For this reason a rigid structure which calls for no excess of internal pressure will almost certainly have to be adopted for airships of the largest class.

* Paper read before the Royal Aeronautical Society

BUILDER OF BIG AIRCRAFT

WAS FIRST TO ADVOCATE THEM

ALFRED W. LAWSON, PRESIDENT OF THE LAWSON AIR LINE COMPANY, PLANNED BIG SHIPS MANY YEARS AGO

Now that the large aircraft has been so successfully demonstrated it is interesting to note that Alfred W Lawson, President of the Lawson Air Line Company, was one of the first of the aircraft manufacturers of the world to advocate their construction and utility

As far back as 1908, Mr Lawson, as editor of the magazine "Fly" which he established frequently called the attention of his readers to the Big Passenger carrying ships of the air that would eventually come and subsequently during the years of 1910-1911 and 1912 he, as Editor of the Magazine "Aircraft" literally filled its pages with his forecast of big ships of the air

In 1911 Mr Lawson as General Manager of the Forman Company of America endeavored to have that Company build big ships, but at that time capital could not be induced to take such an advanced step.

In 1913 Alfred W Lawson entered into an agreement with Johann Schuette of the Schuette-Lanz Airship Company of Germany to establish a passenger carrying air line between New York and Washington Arrangements were under way for this project when Mr. Schuette notified Mr Lawson that the Kaiser had forbid the plans of the Schuette-Lanz Airship going out of Germany

Mr Lawson has spent all of his time during the last twelve years in helping to build up the aircraft industry in America and he has thus gained practical experience from every angle

The big passenger and mail carrying ships that are now being built under Mr Lawson's direction in Milwaukee, Wisconsin, are therefore but the outcome of plans he had thought out years ago and which he strived to interest capital to build them without success.

During the past three years Mr Lawson was General Manager of the Lawson Aircraft Corporation which was principally occupied in building military airplanes. Many new and original types of military machines were designed and built under Mr Lawson's direction during the war

The MT1 for primary training the MT2 for advanced training the MT3 for reconnoissance work and an all steel machine—The Lawson Battler—for trench, infantry and cavalry fighting were right up to the minute in their performances. (The Steel Battler was not finished at the time hostilities ceased)

One thing in particular Mr Lawson takes great pride in, and that is that there has never been a man hurt in a Lawson airplane He is a stickler for safety even at the expense of performance However, he has, up to date, invariably gotten the performance as well as the extra safety put into his machines.

More than a year ago when it was found impossible for steamships to transport all of the airplanes across the Atlantic that America was preparing to build, Alfred W Lawson invented the "Trans-Oceanic Float System" whereby a thousand airplanes a day could be sent streaming across the ocean under their own power

According to this system a number of steamships devoid of their superstructure and known as "Floats" were to be stationed at intervals of fifty miles apart across the Atlantic to act as guide posts and signal and landing stations for all types of airplanes from which fuel and aid could be obtained and repairs made when necessary Land airplanes were to alight upon the decks of these steamships or floats, while flying boats or hydro airplanes were to alight upon the water along side of them.

The plans of this system were given to both the United States Navy and Army officials by Mr Lawson in June 1918 and shortly afterward the same plans were given to the British Navy

Mr Lawson's system made crossing the Atlantic Ocean by airplane a very simple process and a practical every day feat that could be accomplished by any number of ordinary aviators on any sort of airplanes.

The first transatlantic flight by a navy flying boat recently was made according to the principles of Mr Lawson's Float System.

The Navy stationed steamships across the ocean at intervals of fifty miles apart as indicated in Mr Lawson's plans to act as guide posts, signal stations and for fuel and repair ships in case of need.

Events proved conclusively that without these floating stations the Navy flight could not have been made

The failures of F. P. Raynham and Harry G Hawker in their attempts to make non stop flights across the Atlantic proves the futility or at least the uselessness of that system for some time to come

Recent published photographs show that the British Navy has already successfully tried out and adopted steamship floats for land airplanes to alight upon at sea

Had the British Navy stretched these steamship floats across the Atlantic at intervals of fifty miles as the United States Navy did with their war ships, then Harry Hawker, F. P. Raynham or any other aviator could have flown across the ocean with ease and certainty and it would not have been necessary to leave their wheels behind nor break down from overloading with fuel.

The British Navy would then have proved Mr Lawson's system for land machines as the United States Navy proved it for flying boats.

A Lawson Military Biplane, the M T. 2

The semi rigid is a type which has been practically undeveloped in this country The Italians, however, have done a great deal of work on ships of this description, but it appears very doubtful whether, all other things being equal, there is much to be gained by the addition of a rigid keel to a non rigid envelope. The keel of a semi rigid ship has to be sufficiently strong to take the loads of the airship without the assistance of the envelope, because in the event of pressure in the envelope failing the keel would collapse and the ship could not be restored to her correct shape by making good the pressure in the envelope Non-rigids which have lost pressure have frequently buckled in the air to a seemingly alarming extent, but have continued their flight undamaged as soon as pressure has been restored The Italian system of providing a keel capable of taking only longitudinal thrust is an extremely ingenious one, but it is not found in actual practice that very much advantage in overall height of the ship can be affected by this method This, of course, is due to the fact that the points of attachment of the riggings are moved down from the level of the center of the envelope to the level of the keel

The design of the envelope of non-rigid ships is a matter which requires a very considerable amount of careful consideration

The overall height is restricted by the size of the airship shed, and also by the power of the elevators which are required to incline an airship of which the car is far below the center of the envelope If the weight is concentrated and placed close to the envelope, the riggings necessarily lie at a very flat angle and exert a serious longitudinal compression This has to be resisted by a high internal pressure, which in turn causes great circumferential tension and involves the use of correspondingly heavier fabric for the envelope

The general consideration of the rigidity of an envelope is one of very considerable complexity, and may be most conveniently tackled by arranging a model experiment in which the lift of the gas and the distribution of load is reproduced in a small envelope filled with water and inverted, the weight of the water acting downwards corresponding with the lift of the gas acting upwards in the full size ship The load is taken by a number of wires arranged similarly to the riggings and passing over pulleys which support the equivalent of the load of the airship The weight of the planes and other envelope fittings can similarly be represented Pressure in the envelope is maintained through a tube connected to a water reservoir, the level of which can be varied. A convenient method of determining the pressure in the water model, which shall correspond to similar pressure in the airship, can be obtained as follows —The pressure in an airship could be maintained at any desired value by fitting an open-ended hose to the bottom of the airship and filling the airship with gas until gas issues from the lower end of the hose If the end of the hose is at a distance of M metres below the bottom of the envelope the pressure of gas at the bottom of the envelope wall, as explained later, be M millimetres of water above atmosphere Similarly in the water model, the height of the free surface of water above the envelope corresponds to the internal pressure at that point and as the dimensions of the model and the envelope have been arranged correctly to scale, the comparison is a direct one For example, if the diameter of the airship is 15 m, and it is desired to maintain a pressure of 20 mm of water at the bottom of the envelope, the length of the open hose must be equal to 20 m, that is, 20/15 of the diameter of the envelope This is reproduced in the water model by maintaining the water surface at a distance above the envelope equal to 20/15 of one diameter

The method of carrying out these experiments is a very simple one The various loads are distributed along the envelope and the pressure is reduced until the fabric begins to pucker at some point The value of this pressure is noted The distribution of load may then be varied in order to reduce the compression in the fabric at this point

It is desirable to arrange the water model so that the whole system can be inclined up or down at one end in order to reproduce the conditions of the airship pitching Provision against pitching occasions greater difficulty than the mere satisfactory suspension of the load when the ship is on an even keel It is not possible to give any simple rules for arranging the rigging of the non rigid ship, but one system which has been found generally satisfactory is to lead wires from points distributed along the envelope at intervals suitably proportioned to the lift of gas at each section This provides for the suspension of the load on an even keel Independent wires should then be provided to prevent "fore and aft" motion of the airship car when the ship becomes inclined It will easily be seen that the tendency to deform the envelope very materially reduces as the distance of the load from the envelope is increased and also if the load can be divided into one or more separate units

The point at which the riggings are attached to a circular envelope is necessarily some distance below the axis If it is possible to raise the level of these points of suspension to a higher point on the envelope, the height of the ship can be correspondingly reduced

Further, the direct longitudinal compression due to the riggings is applied at a point considerably above the axis of the ship, that is, at a point where the difference of pressure and therefore the longitudinal tension of the ship is greater than at the lower levels This principle was satisfactorily achieved in the system invented by a Spaniard, Sr Torres-Quevedo, and subsequently developed by the Astra Co of Paris.

The envelope is made of trilobe cross section and the riggings are led into the envelope at the bottom ridge and parted into two fans of strings secured to points along the top ridges. To constrain the envelope to this trilobe shape, curtains of ordinary unproofed fabric are laced to the ridges. These do not, however, divide the ship into separate gas compartments.

The system adopted by the Parseval Co is to provide a strong rigging band as a kind of girdle on the lower part of the envelope. To this the car is attached The shape of the envelope is maintained by reinforcing bands of webbing stuck to the surface of the envelope along trajectories, the position of which is determined by experiment

Both these systems and also the semi-rigid design involve considerable complexities and are only rendered necessary in order to suspend a concentrated weight as close as possible to the envelope If, however, it is not necessary that the weight should be concentrated and it is possible to distribute the majority of the weight in a number of separate cars or along the envelope itself, these systems and the complexities they involve can be abandoned

Structure of Rigid Airships

The framework of a rigid airship consists of a number of rigid longitudinals connected by a number of transverse members, which form rings at intervals along the length of the ship Each of these rings is braced in its own plane by a number of radial wires. The gas bags are placed in the compartments between these bulkheads of radial wires The outer cover is stretched over the outside of the frame-work

In order to transmit the upward pressure of the gas bags to the framework, nets are provided and attached to the inner edges of the various rigid members of the framework

The weights carried by the ship are mostly placed in a strong keel which runs along the bottom of the ship The function of the keel is primarily to distribute the load of these weights to the main transverse sections of the ship The cars which are suspended below the hull of the ship are also attached at points which bring the load on to the main transverse bulkheads. Special lift wires are arranged, in addition to the radial wires, to transmit the load of the keel to the upper part of the framework

If, for any reason, one gas bag becomes much less inflated than those on either side of it, there will be considerable pressure tending to bulge the radial wires towards the empty bag Tension in these wires may produce very serious compressive strain in the transverse members and in order to assist in resisting the bulging action an axial wire is often led along the axis of the ship and secured to the wires of each bulkhead

Sub-division of Gas Space in Large Airships

The necessity for dividing the gas space into a number of separate compartments is not primarily due to the possibility of losing the whole of the gas from one compartment by leakage from external damage to the fabric. As long as an airship remains on an even keel the pressure of the two ends of the ship will be approximately the same, but if the airship be now placed vertically head upwards the excess of the internal pressure at the top of the ship over that in the air outside will be considerably greater than that excess at the bottom of the ship This is due to the difference in weight of a column of

air and a column of hydrogen equal to the length of the ship The same variation of internal pressure will obtain in a lesser degree when an airship in ordinary flight has one end raised considerably above the other It is convenient to remember that this variation of the difference of pressure amounts to 1 mm for each metre difference in level

U S. NAVAL AIRSHIP F-1 CAPACITY, 95 000 CU FT ENGINE, 125 HP UNION SPEED, 55 M P H LENGTH, 162 FT DIAMETER, 33½ FT

Photo U S Naval Air Service

In the case of a non rigid, which has to maintain a minimum difference of pressure between the inside and outside of the fabric of 15 mm the effect of having the bow of the ship raised considerably above the stern will produce a large increase of pressure difference in the bow and consequently an increase in tension of the fabric at that point In a short ship this increase of pressure due to inclination of the ship is small, but in ships of great length the increase would be a serious one. For this reason it becomes necessary to divide a long ship into a number of compartments, but this is only effective if the bulkheads, which isolate one compartment from another, are capable of maintaining difference of pressure between their two sides In a rigid airship which has a number of separate gas containers arranged inside its structure this division is effective There is, therefore, no accumulation of pressure at the higher end of the ship The radial wires which form the bulkheads between the gas bags are capable of withstanding a certain difference of pressure between the gas on the two sides of the bulkhead

Sub-division of the gas space is also desirable in order to avoid the surging of gas from one end of the ship to the other An airship partly filled with gas would, if not sub-divided, tend to be very unstable as the gas would tend to run to whichever end happened to be the higher In a non rigid ship this surging is satisfactorily avoided by sub-dividing the air space into a number of ballonets so that the air in each can only move a short distance forward or aft

Attachment of Rigging Wires to Fabric

A steel wire may be attached to fabric and communicate the load to the envelope by passing it through a tubular D-piece, round the outside of which are laid strips of webbing. These are stuck to fabric foundations which are extended over a small portion of the envelope. This construction serves satisfactorily to communicate the tension in the wire to the envelope and to give reasonably good distribution of stress.

Blowers

In order to maintain the pressure in a non-rigid envelope, blowers of the ordinary low pressure rotary type were originally provided These were driven either from the main engines or by separate small gasoline engines They occasioned, however, a very fruitful source of breakdown. It was subsequently found possible to replace them by what is termed a blower pipe, arranged to collect air from the slipstream of the propeller and to discharge it into a duct which distributes it to the various ballonets of the ship The energy required to provide this air at high pressure was derived at the expense of a slight increase in head resistance, and in order to avoid this, arrangements were made whereby the blower pipe could be hinged about its top end and folded up along the under surface of the envelope

A method which is employed in Italian airships is to derive the pressure from the extreme bows of the envelope The sufficiency of this pressure will be discussed later

The distribution of this air to the various ballonets necessitated the use of shut-off and non-return valves. These were originally made from sheet aluminum and gave very considerable trouble. It was found, however, that fabric valves arranged in the form of a sleeve, which can be partially turned inside out, gave very effective results This valve is referred to as a "crab-pot"

To enable pressure to be maintained when the main engines are not in use an auxiliary blower is necessary. The rotary type of blower driven by a separate small engine was used for a considerable time, but proved capable of improvement both as regards space occupied, reliability and efficiency. A new type of blower was devised and consisted of a small specially designed propeller discharging into a shaped casing, shaped so as to avoid as far as possible all loss due to eddies. The shape of this orifice was very carefully determined and a large boss fairing was fitted to the propeller.

Careful tests made by measuring the horse-power and output of air showed that for the same horse-power and discharging against the same head the new blower would deliver three times the amount of air previously discharged by the rotary blower.

Airship Valves

In order to prevent the pressure in the envelope exceeding a predetermined maximum and causing danger of bursting, valves are provided to relieve the pressure in the ballonets and in the gas space. The valves are made automatic in their action and the gas valve is set to blow off at a pressure somewhat in excess of that adopted for the air valve, thereby ensuring that an increase of pressure is first corrected by discharging air from the ballonet valves. If the rate of discharge is insufficient the gas valve then lifts, but the discharge of gas is avoided wherever possible.

It will be realized that if these valves were constructed and spring loaded in the ordinary way, the pressure of the valve on its seating would be gradually reduced as the pressure inside the envelope increased. When blowing off point was nearly reached there would be a considerable period while the valve was only very lightly pressed on to its seating and when leakage was extremely likely to take place. The mechanism of the valve was, therefore, arranged so that the force tending to cause the valve to open decreased as the valve opened, and the result produced was, therefore, that the valve would remain on its seating until the predetermined pressure was reached. It then opened wide and would remain open until the pressure had fallen slightly below that at which the valve opened. This gives a very determined action and materially reduces the amount of leakage from a valve while it is "stuttering" in the very slightly open position.

The gas valves used for relieving pressure in a rigid airship are fitted in the lower part of the bag where they can be reached from the keel gangway. They are automatic, but are much larger and loaded to a much lower pressure. In addition to these relief valves, hand-operated maneuvering valves are fitted at the top of most of the bags so that gas can be released in order to alter the trim of the ship.

Bow Stiffening for High Speed

The pressure which it is necessary to maintain in a non-rigid envelope depends upon two things. Firstly, the pressure which is necessary to prevent the envelope from collapsing under the influence of the rigging tension; and secondly, the pressure which is necessary to prevent the bow of the envelope being blown in, due to the excess of external pressure caused round the bow of the envelope by the motion of the airship forward.

It is found that the excess of pressure which takes place at the bow of the ship extends for only a short distance aft. By reinforcing this area it is possible to fly with an envelope pressure considerably lower than the external pressure at the bow of the ship.

This stiffening of the bow becomes a matter of greater importance as the speeds increase. There is always the possibility in "bumpy" weather, when the height of the ship varies rapidly, that the pilot may let his pressure fall momentarily too low. The bow of the envelope then blows in and forms a curious concave cup shape in which it remains till a speed is reduced or the pressure is raised. No damage will probably be done so long as the reinforcement of the bow is not of such a nature that it will break and puncture the envelope. It may very probably be necessary to provide a separate small compartment at the bow and kept at a higher pressure than that of the rest of the envelope. This would allow high speeds to be attained without a corresponding increase in envelope tension.

Planes

In order to stabilize the motion of the ship it is necessary to provide the envelope at the after end with planes. These are provided at their after edges with rudders capable of steering the ship either vertically or horizontally. The construction of these planes somewhat resembles that of the wing of an airplane. Fabric is stretched over a framework and is doped in order to render it taut. The surfaces are, however, practically flat and the loading is considerably less than that provided for in an airplane.

The planes are supported from the surface of the envelope by guy wires attached to suitable points on the envelope, and are prevented from pushing their inner edges into the envelope by skids or wooden bearers. The importance of the rigidity of this resistance to inward thrust is very often under estimated. A small inward movement of the foot of the plane allows the plane as a whole to set over a serious angle. This lack of rigidity in the planes has a serious influence on the stability.

The maximum intensity of air pressure occurs towards the forward edge of the planes, and it is therefore desirable that the leading edge should be short. The long narrow plane, increasing in width as it goes aft, is therefore adopted in preference to that of large aspect ratio which, although aerodynamically more effective, would be much more difficult to hold with adequate rigidity.

The planes of a rigid ship are attached rigidly to the hull framework. In the latest German ship these planes are made some 6 ft thick at the root, and faired off into the rudder and tapered to the outer edge. They are, therefore, almost totally self supporting and require no guy wires.

(To be concluded)

DH-4A Converted Into a Mail Airplane by the L-W-F Co for the New York-Chicago Service

Tests of Moisture and Water Resistant Coatings

By Henry A. Gardner

Institute Industrial Research

It is obviously necessary to render fairly waterproof the pontoon, float, or hull surfaces of seaplanes, flying boats, or other craft constructed of wood. If this is not accomplished, considerable water will be admitted, which will add greatly to the weight and materially diminish the speed obtainable and the general efficiency of the craft. Unfortunately, the word "waterproof" has been used to describe the film that is produced by protective coatings of nearly every class, whereas, none should not be so classed. In order to determine the actual value of various types of coatings that are used by the boat builder for finishing small craft a series of tests were made, which have afforded considerable data of a valuable nature.

Before describing these tests it might be well to point out that wood is a cellular substance, the fibrous part of which absorbs large quantities of moisture. When the fiber becomes saturated with moisture, further quantities of water may be admitted in liquid form. This water will be held in the cellular cavities of the wood. When wood that has absorbed either water vapor into its fiber or liquid water into its cellular cavities, is submitted for a considerable period of time to drying, both the water and the moisture pass out and the wood is restored to its original so-called air-dry form which under normal conditions of testing and fabrication, should contain in the neighborhood of 11 to 15 per cent of moisture. Spruce, for instance, such as is used in the manufacture of the various parts of seaplanes, is always conditioned to the above moisture content before working.

For making the tests, there was selected a series of carefully dressed panels of airplane spruce and of yellow poplar. The edges of each panel were carefully rounded and all surfaces made smooth. The panels were 4 in. x 8 in. x ½ in., there being thus afforded by each panel a total area of approximately one square foot. After drying the panels for ten days in the laboratory at a temperature of 70 deg. Fahr., they were given three coats of the compounds that were used in the tests, allowing ample periods for the hard drying of each coat. After the third coat was dry the panels were allowed to dry for a further period of ten days, and were then carefully weighed and placed in a specially constructed moisture cabinet kept at a temperature of 100 deg. Fahr., with a relative humidity of 95 per cent. At the end of a period of seven days the panels were removed from the cabinet and the surfaces wiped off, to remove any extraneous water that had been deposited by condensation. The panels were then carefully weighed and the gain in weight due to moisture absorption was recorded. After a period of seven days' drying at 70 deg. Fahr. they were reweighed and immersed in a specially constructed tank containing distilled water, being hung from the bottom so that they would float upward. The completely immersed panels were allowed to soak for a period of seven days. They were then removed, the surfaces carefully wiped, and weighed. The gain in weight due to water absorption was recorded. The panels were again allowed to dry for seven days at a temperature of 70 deg. Fahr. and reweighed to determine the amount of water retained within the structure of the wood.

The materials used for coating the wood panels need but little description. The raw linseed oil and boiled linseed oil conformed to Navy Department specifications. The shellac, acetate airplane dope, nitrate airplane dope, spar varnish, and enamels conformed to Aeronautical Specifications of the Navy Department. All of the enamels were made with No. 3 varnish containing 25-30-40 and 15 per cent respectively, of pigment. In the charted results these enamels are referred to as No. 4 *a*, *b*, *c*, and *d*, respectively. The first three contained lead and zinc pigments, while the last contained aluminum powder as the pigment. The oil (N) dope was a cellulose nitrate dope containing a drying oil, and the same material was used in combination with gray pigment to form the pigmented oil (N) dope. The panel painted with oil-graphite was first treated with a flat drying carbon black-linseed oil paint. The graphite was then dusted on while the film was tacky. This operation was repeated until a smooth surface was built up, two coats being necessary for this purpose. The panel coated with varnish graphite was treated with two coats of No. 3 spar varnish containing 20 per cent of graphite. Dry graphite was then dusted on the film while it was still tacky, and by polishing with burlap a bright, smooth surface was developed.

The results which are tabulated herewith, expressed in ounces of water gained per square yard, show that there is a marked difference in the amount of moisture and the amount of water which may be absorbed through films of different types. The results also show that while a film may be relatively moistureproof, it may not be waterproof.

Another interesting feature is shown by the apparent ability of some films to allow large quantities of moisture or water to pass through into the wood but relatively small quantities to pass out after being submitted to drying, thus allowing the wood to retain large quantities of water. The acetate and nitrate dopes and the oil graphite are representatives of this class.

Special attention is directed to the very large amount of water absorbed through raw linseed oil films, as compared to the amount absorbed by the films of spar varnish. It would seem evident from these results that spar varnish forms either a more continuous and less porous film, or one that is less subject to intermolecular absorption. The passage of water through a paint film is probably due to osmotic action, the film acting as a semi-permeable membrane. With increase of temperature and vapor pressure, increase of penetration is shown. The water may also pass through in some cases by first forming an emulsion with the film, although such action may probably be considered as playing a minor rôle in the phenomenon. If a paint should form a film that is absolutely impermeable it might be unsuited for use on certain types of wood construction (dwellings), as the moisture in the wood is continually being drawn out to the surface by the action of the sun and would tend to cause blistering of an impermeable film. A film that shows only slight permeability to water but which allows water which is in the wood to escape freely, without affecting the film, should be considered satisfactory for most small-boat protection.

It should be noted that some panels coated with No. 4 wing enamel,* which is composed of No. 3 spar varnish and pigment, gave even better results than the spar varnish alone, thus indicating the value of a percentage of pigment in rendering films more waterproof. This may to some extent be due to the thicker films which result from the application of an enamel. It should be further recorded that of the four grades of No. 4 wing enamel used, slightly better results were shown by those containing a high percentage of pigment as compared with those containing a relatively low percentage. The amount of water shut out, however, through the addition of a large amount of pigment may not be sufficient to justify the use of a heavier enamel, as such an enamel would increase the initial weight of a flying-boat considerably. Very good results were however shown by the No. 4 (*d*) enamel, which contained a relatively small percentage of pigment (aluminum powder).

The results obtained with the oil-graphite dust treatment of hull surfaces which has been used by the British to some extent, were poor as compared to the present American practice of using No. 4 enamel. When No. 3 spar varnish is used in the British treatment, in place of oil, very good results were shown.

It will be observed that collodion dopes, or acetate dopes, are not to be compared with spar varnish as water excluders, although the dope designated as N, which contained a substantial percentage of varnish oil, gave much better results than the other dopes, which, incidentally, did not contain oil. Since some aircraft makers have often used dope in place of varnish for moisture-proofing woodwork, the above results would indicate that such practice should be discontinued.

The low moisture and water absorption shown by the shellac coated panels is most interesting, as it has heretofore been be-

* Navy Gray Enamel—Aeronautical Specifications C and R No 4 B

lieved that shellac was subject to rapid water absorption. The fact that shellac coatings almost immediately turn white when placed in water may be responsible for such belief. This whitening of the film should apparently not be attributed to water that has passed through the coating but probably to the hydration of the outer surface of the shellac film. From the standpoint of durability however, shellac has proved very inferior to spar varnish when exposed to sunlight and the atmosphere for long periods of time.

A further series of experiments were made with some of the enamels by applying four coats to new panels and then submitting the panels to the same type of water absorption

Spruce Panels.

Material	Gain in moisture cabinet gr. per sq. yd.	Gain in water tank i.e. per sq. yd.	Water retained after drying gr. per sq. yd.
Bare Wood	1.04	37.83	1.45
Raw Linseed Oil	6.01	23.20	2.18
Boiled Linseed Oil	4.80	12.50	2.74
Acetate Dope	3.85	20.25	6.70
Nitrate Dope	4.18	21.30	4.73
Oil N Dope	2.34	2.45	3.32
Pigmented Oil N Dope	2.04	3.14	3.88
Spar Varnish No. 3 (a)	.87	.57	.32
Spar Varnish No. 3 (b)	.78	3.38	1.27
Enamel No. 4 (a)	.13	.68	.36
Enamel No. 4 (b)	.48	1.39	.77
Enamel No. 4 (c)	.77	1.75	1.37
Enamel No. 4 (d)	.24	1.80	1.46
Shellac	.32	1.48	1.21
Oil-Graphite	2.64	33.22	14.10
Varnish-Graphite	1.31	3.32	1.48

Yellow Poplar Panels

Material	Gain in moisture cabinet gr. per sq. yd.	Gain in water tank gr. per sq. yd.	Water retained after drying gr. per sq. yd.
Bare Wood	8.34	47.78	3.20
Raw Linseed Oil	7.43	21.81	2.70
Boiled Linseed Oil	5.77	15.80	2.30
Acetate Dope	5.20	35.48	8.20
Nitrate Dope	5.00	14.10	5.90
Oil N Dope	2.40	4.58	3.24
Pigmented Oil N Dope	.29	3.02	2.95
Spar Varnish No. 3 (a)	1.40	3.42	2.81
Spar Varnish No. 3 (b)	1.32	2.88	2.20
Enamel No. 4 (a)	.18	1.18	.96
Enamel No. 4 (b)	.78	1.32	1.21
Enamel No. 4 (c)	1.34	3.20	2.44
Enamel No. 4 (d)	.47	1.04	.72
Shellac	.47	2.01	1.89
Oil-Graphite	2.85	20.60	11.80
Varnish-Graphite	.82	2.42	1.50

Water Absorption of Panels with 3 and 4 Coats of Enamel

3-Coat Work Gain in water gr. per sq. yd.		4-Coat Work Gain in water gr. per sq. yd.
1.18	Enamel No. 4 (a)	.19
1.04	Enamel No. 4 (b)	.27

apparatus as described above. A remarkable reduction in absorption was shown. The results, which are rather astounding, would indicate that the application of four coats of enamel to boat construction would be well repaid by the very high water-resisting films thus obtained.

It is the writer's belief that the type of enamel that has proved so successful in these experiments should be used to a much greater extent than heretofore. Its highly successful use on the hull surfaces and also as a protective over the dope on the fabric covered wings of several hundred seaplanes has demonstrated its value and possibilities. It may have application as a general protective for exterior marine work and prove more successful than some of the paints now in use for such purpose.

Tests were not made of the newly devised process of the Forest Products Laboratory, of waterproofing wooden surfaces, such, for instance, as propellers. In this process the wood is coated with a varnish and then aluminum leaf is applied. The aluminum leaf is subsequently finished with varnish or paint. It is understood that the highest degree of moisture and water resistance is afforded by this process which might find application for use on certain parts of small boat construction.

NC-4 Reaches Plymouth

The United States naval seaplane NC-4, Lieut.-Comdr. A. C. Read, U. S. N., commanding, concluded her epoch-making cruise across the Atlantic on May 31, when she reached Plymouth, England, having covered the air line distance of 3925 sea miles from Rockaway in 52 hr. 32 min. flying time. The total elapsed time from start to finish of the trans-Atlantic flight of the NC-4 was twenty three days 23 hr. 34 min.

Commander Read reported on the last legs of the ocean flight to the Navy Department as follows:

"NC-4 left Ponta Delgada 10.18 a. m., G. M. T., May 27. Wind 200 deg., 13 miles, visibility good. Sighted all destroyers except No. 3, which was missed on account of compass jarring out. Speed, first part, 88 knots. Rho uneventful. Landed Lisbon 8.01 p. m. Personnel and seaplane in excellent condition.

"NC-4 left Lisbon May 30, 5.29 a. m. Weather normal, except rain squalls. Favoring wind. At 7.05 leak discovered in port engine. Necessary to land for repairs. Landed Mondego River 7.21 and repaired leak. Necessary to wait high tide, about 2 in afternoon. Impracticable to make Plymouth same day. Left 1.38 p. m. for Ferrol Harbor, Spain. Changes in course necessary, dodging rain squalls. Otherwise uneventful. Landed 4.47. Two destroyers arrived to assist.

"Under way 6.27 next morning, sighted only two destroyers on account of squalls and thick weather. Circled over Brest 11.05, very thick in vicinity, frequent rain, head wind across channel. Sighted Plymouth nearly ahead at 1.12 p. m. and landed 1.26 p. m., G. M. T. Officially received by Mayor and Admiral Thursby. Personnel and seaplane in excellent condition. Three motors same as installed at Rockaway. Fourth installed at Trepassey."

Change in Aircraft Insignia

In accordance with an agreement between the Secretary of War and the Secretary of the Navy to change the distinguishing insignia on aircraft the following regulations are published for the information and guidance of all concerned:

The design shall be a red circle inside of a white, five-pointed star, inside of a blue circumscribed circle. The circumference of the inner circle shall be tangent to the lines forming a pentagon made by connecting the inner points of the star. The inner circle shall be red, that portion of the star not covered by the inner circle shall be white, and that portion of the circumscribed circle not covered by either the inner circle or star shall be blue, the colors to be the same shades as those in the American Flag.

These insignia shall be placed on the upper and lower surfaces, respectively, of the upper and lower planes of each wing in such position that the circumference of the circumscribed circle shall be tangent to the outer tips of the planes. One point of each star shall be pointed directly forward and unless otherwise specified the diameter of the insignia shall be 60 in.

The insignia for the rudder shall be three equally wide bands, red, white, and blue, and both sides of that portion of the rudder which are in the rear of the rudder post shall be striped parallel to the vertical axis of the airplane. The blue band shall be nearest the rudder post, the white band in the center, and the red band at the tail of the rudder; the colors to be the same as hereinbefore-mentioned.

French Flight Performances

Lieutenant Roget, pilot, and Captain Coli, passenger, both of the French Air Service, established on May 25 a new record for single-engine airplanes by flying from Paris to Kenitra, near Rabat, Morocco, a distance of 1116 land miles, which they covered in 11 hr. 50 min. without alighting en route. This flight was intended as the initial leg of a projected transatlantic flight from Dakar, French West Africa, to Pernambuco, Brazil. This attempt will have to be temporarily abandoned, however, as the machine, a Bréguet biplane fitted with a 400 hp. Renault engine, was damaged upon landing on difficult ground.

On June 7 Sub-Lieutenant Casale reached, in a single seater, an altitude of 9,500 meters, thus establishing a new world's record.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